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Interactive comment on "Spatial and temporal characterization of SCIAMACHY limb pointing errors during the first three yearsof the mission" *by* C. von Savigny et al.

C. von Savigny et al.

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Reply to comments by Referee #1 (Holger Walter)

1) More discussion of the physical processes and model assumptions that may lead to the observed pointing errors.

We agree with the referee that the submitted version of the manuscript lacked a more detailed discussion of the physical processes that may be responsible for the retrieved pointing errors. This was also criticized by referee #2 (comment 3) and referee #3 (comment 1). We addressed this comment by the following changes:

a) A brief overview of the relevant processes that may lead to limb pointing errors was included in the introduction

b) A brief summary of the pre-launch pointing accuracy estimates as presented by Schwab et al., 1996 was included in the introduction

c) A more detailed description of the modifications made to the orbit-propagator model in December 2003 that improved the seasonal variation of the tangent height errors was included in section 3.

d) A discussion of possible causes of the constant offset of about 1 km after December 2003 was included in section 3.3.

e) A discussion of the aspect whether the seasonal variation after the December 2003 update is possibly due to the used ozone climatology was included in section 3.3

We hope that including these discussions improved the manuscript.

2) Page 3704, line 4: - How has it been recognized that the TH information provided in the data files contains errors

There were several different indications for pointing errors:

a) The ozone concentration profile peaked near 30 km at tropical latitudes in some cases. Although there is a certain natural variability of the ozone concentration peak altitude, 30 km is too high.

b) Measurements of the altitude of the Noctilucent cloud (NLC) signature in the SCIAMACHY limb radiance profiles. Optically visible NLCs have a remarkably constant altitude of about 83 - 84 km in the northern hemisphere. Although this is only a crude pointing determination method, the apparent NLC altitudes were systematically higher than the present knowledge.

c) Initial tests with a monochromatic knee approach (at 305 nm as done for OSIRIS (Sioris et al., 2003)) showed indications for pointing offsets.

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d) Elevation mirror discontinuities during sun-acquisition measurements indicated pointing errors. The sign of these errors was consistent with the SCIAMACHY limb pointing errors.

e) Retrievals of CO2 (near 1560 nm) and O2 (b-band) profiles from solar occultation measurements used to correct the scientific occultation data products developed at IUP Bremen also indicated pointing errors [Meyer et al., 2005].

f) The IMK-MIPAS team reported MIPAS limb pointing errors early during the Envisat mission. MIPAS is located on the other side of the spacecraft and views in the opposite direction.

- When do you classify a given TH to be correct?

Good question! Generally, using pointing retrieval with TRUE in principle if the retrieved TH offsets are larger than the retrieval errors. But as explained in the previous paragraph there were several different indications that the pointing was erroneous, and TH errors of 2.5 km and more were observed. Therefore, it was more than obvious that the THs were wrong.

- Short description of possible physical error sources causing the mispointing. Expected pointing error

A paragraph was added describing the most important pointing error sources documented in a technical note by Schwab et al.. Interestingly, the estimated total elevation pointing error is larger than the values retrieved with TRUE and estimated by the validation exercises, namely 0.061 corresponding to about 3.4 km. If the actual pointing performance were only as good (or poor) as the pre-launch pointing error budget, then the profile retrievals were hardly good enough for scientific purposes.

3) Page 3705, line 8: ellipsoidal vs. spherical coordinate system

We would like to make a few general comments on the technical note by van Soest [2005b], because we believe, that the issue raised in this tech note - an inconsistency

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between the elliptical coordinate system used in the orbit propagator model and the spherical atmosphere assumed in the retrievals - is not a real issue for the limb retrievals.

Since the Tech note caused many discussions at several SCIAMACHY meetings we will now give a brief summary of our understanding of the van Soest tech note (perhaps we missed an important point):

van Soest found that the Earth radius listed in the SCIAMACHY Level 1 files is the curvature radius at the sub-satellite point, because (a) it is symmetrical with respect to the equator and (b) assumes a minimum value at the Equator. On an ellipsoidal Earth the curvature radius does of course depend on the latitude.

Then van Soest determined the tangent heigths in a spherical atmosphere using simple trigonometry based on the SCIAMACHY LOS (line of sight) viewing angle at the satellite point and the Earth's curvature radius at the sub-satellite point, since only this radius is included in the Level 1 files. These tangent heights are then compared to the engineering tangent heights provided in the SCIAMACHY level 1 files, and a tangent-height dependent difference of up to 350 m is found. This difference roughly exhibits an uneven behaviour with respect to the equator. From the fact that the tangent heights in the Level 1 files differ from the ones determined with equation 1, we conclude that the SCIAMACHY Level-0-to-1 processor does not simply use equation 1 to determine the tangent heights.

To this point we understand van Soest's reasoning and agree that the tangent heights determined with equation (1) of the technical note will differ from the tangent heights listed in the Level 1 files, which are based on a more accurate elliptical system. However, we now argue, that the difference between these different ways to obtain tangent height information has no relevance for the limb retrievals. And the reason simply is, that we do not calculate the tangent heights from the line of sight elevation angle and the curvature radius at the sub-satellite point, but use the "correct" tangent height information from the data files.

What is important in this context is that the tangent heights in the Level 1 files really correspond to the physical tangent heights in the atmosphere. The retrieval now assumes a spherical atmosphere with a certain Earth radius (so far we actually used the mean Earth radius of RE = 6371.3 km), which may be different from the actual Earth radius at the given latitude. Still, the tangent heights sort of correspond to the same altitudes in atmospheres with different Earh radii. The differences between two different atmospheres (with different Earth radii) are differences in the light paths in the far and near field. To test this effect, we performed TRUE pointing retrievals for a sample orbit (Orbit 17521) with different values of the Earth radius: the mean Earth radius of 6371 km, the polar radius of 6356 km and the equatorial radius of 6378 km. The mean difference between the mean radius and the polar radius was found to be about 10 m, and is almost negligibly small.

Therefore, we argue that the impact of the different coordinate systems cannot be the cause of part of the apparent difference between the engineering tangent heights and the TRUE retrievals.

Again, we do not state the the difference between the engineering tangent heights and the ones derived from equation 1 in van Soest is wrong, but we argue that this difference is not relevant for the limb retrievals.

We decided not to include a discussion of this aspect in the manuscript, because we believe that is it (a) not a real issue here - its impact is much smaller than other sources of error - and (b) because a detailed discussion of the statements of the van Soest tech note and the arguments against would require lengthy explanations and would be beyond the scope of this contribution.

4) Page 3705, line 19: Impact of calibration errors (constant offset or spatial straylight)

In terms of a constant offset we have no indications that the limb obervations are af-

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fected by an incorrect dark (or leakage) current correction. The referee is of course absolutely right, that such a calibration error may have an impact on the pointing retrievals. However, due to the fact that the knee really is a maximum in the limb radiance profiles - and most of the information comes from the altitude of this maximum - the retrievals should not be affected by constant offsets very much, since the altitude of a maximum does not change, when an offset is added.

Spatial straylight is indeed a problem with the SCIAMACHY limb scattering observations, however, it is mainly the visible channels that are affected by it. There are also indications for spatial straylight in channel 1 (the channel used here), but it becomes important only above about 75 km. For the present pointing retrievals we use the 35 - 50 km tangent height range. We were also worried about the possible impact of the spatial straylight contamination on the pointing retrievals, but I'm afraid, that an accurate characterization of the straylight contamination in the spectral range and the tangent height range used is basically impossible. In principle, one could compare modelled and measured limb radiance profiles for a well characterized scenario (i.e., background atmosphere, absorber profiles, ground albedo, aerosol loading etc. are well known) and assign the differences to spatial straylight. But we found that for the spectral and tangent height range used here, the inaccuracies in background atmosphere etc. are too large to produce significant results. Conversely, this implies that the spatial straylight cannot be a major problem here. Furthermore, the TRUE fits show no indications of systematic errors that may be due to spatial straylight.

In general, the UV range is not affected as much by spatial straylight as the visible and NIR. This is due to the fact that the atmosphere becomes optically thick at fairly high tangent heights, and the limb radiances do not increase exponentially as one moves down to the lower tangent heights.

Unfortunately the spatial (vertical) point-spread-function (PSF) for limb viewing geometry has not been measured pre-launch in the lab with sufficient angular sampling. It was measured for off-axis angles ranging from -10 degrees to +10 degrees in steps of

1 degree. But from the perspective of the instrument the tangent height range between 0 and 100 km corresponds to only 2 degrees.Van Soest [2005b] used these lab measurements to simulate the effect of spatial straylight on modelled limb radiance profiles, and interpolated between the measured points of the spatial point-spread function. In his Fig. 12, the effect is a significant shift in the knee altitude for a wavelength of 300 nm. However, this modelled effect is much larger than the actual effect, because due to the incorrect interpolation of the PSF too much vertical smoothing is done on scales of 10 - 30 km. We have no reason to doubt that the measured values of the PSF at 1, 2, 3... degrees off-axis angle are unrealistically large. But the PSF decreases much faster for small off-axis angles than modelled with a simple interpolation. We found that a Gaussian function yielding the the normalized signal at angles of ś 1 degree shown in Fig. 11 of van Soest [2005b] has a FWHM of about 0.63 degrees, corresponding to a tangent height difference of about 35 km. This value is completely unrealistic. The reason of course is, that a Gaussian is not a good approximation of the actual SCIAMACHY limb point spread function over a larger range of off-axis angles.

In summary, we think that the spatial straylight contribution in the UV-B and for the tangent height range used here is not - carefully put - a major error source. In fact, there are several indications (listed above) that it is small compared to the other sources of error.

5) Page 3706, line 20: Explanation of orbit propagator model. What was changed?

Thanks for pointing this out. I now realize that more information on the orbit propagator model is necessary.

The onboard orbit model and the orbit propagator model are identical.

The on-board orbit propagator model is re-initialized twice per day. This is done by uploads of initialization files - the so-called state vector - to the spacecraft. The changes applied in December 2003 consisted of altering the way in which the state vector is determined. In detail, a reference system inconsistency was eliminated: the state vector was previously determined on-ground using the mean-of-2000 coordinate system (MO2K) - whereas the software controlling the SciAMACHY scan mirrors uses a different system, i.e., the true-of-date system (TOD). This change lead to the reduction in the amplitude of the seasonal variation of the platform attitude errors and in consequence the instrumental pointing errors.

6) Page 3708, line 16: - Could the remaining seasonal variation in TH offsets results from the used ozone climatology?

Another good point! We cannot entirely exclude the possibility that the apparent seasonal variation after December 2003 is caused in part or predominantly by differences between the assumed ozone climatology and the actual ozone field. The Kaiser et al. [2004] sensitivity studies showed that changing the entire ozone profile by 20 % leads to differences in the retrieved TH offsets of 1 km at the most. On average, the differences are much smaller. The observed seasonal variations in 2004 have an amplitude of about 250 m. This could be caused by differences between the actual ozone field and the climatological one of less than 10 %, which is probably well possible. However, the sun-acquisition measurements mentioned in the new version the paper - where discontinuities in the elevation mirror position occur when the sun-follower is switched on - also still exhibit a seasonal variation after the December 2003 orbit model update with an amplitude of about 250 m as well [Stefan Noël, personal communication, May 2005]. However, the seasonal variation in the TRUE retrievals and the sun-acquisition measurements are phase shifted by several months. Although this point is not yet fuly confirmed, the ESA satellite engineers stated that this seasonal variation is due to the fact that the solar occultation measurements are always performed at high and mid-latitudes (in the northern hemisphere), whereas we only used the tropical measurements for the TRUE pointing retrieval. As just mentioned, this aspect is presently under investigation, but it seems likely that the seasonal variation observed after December 2003 is to a large extent due to remaining problems with the orbit propagator model and not mainly caused by the ozone climatology. A discussion was added to section 3.3

- What is the impact of ozone cross section uncertainties on the pointing retrievals

Tests showed that scaling the entire ozone cross section by factors of 0.98 and 1.02 leads to mean differences in the retrieved TH offsets of about 60 m with a standard deviation of about 30 m. A short paragraph on this was added to section 2.

- Impact of background atmosphere

This point was also raised by referee #2. Please see response to comment 1 by referee #2

- Retrievals with different radiative transfer model

It would certainly be a good idea to compare the pointing retrievals made with SCIA-RAYS with retrievals performed with SCIATRAN. However, this is far beyond the scope of this study.

7) Page 3710, line 10: Statistical overview showing the possible improvement of the ozone profile retrieval due to the pointing correction

This aspect was also raised by referee #2. A fairly comprehensive validation study (Brinksma et al. 2005) was also submitted to the ACP special issue on SCIAMACHY validation, using 5 months of SCIAMACHY ozone profile data in 2004. Although in this comparison the IUP ozone profiles were not individually pointing-corrected using the TRUE pointing retrievals - instead a constant TH offset of 1.5 km was subtracted from the THs of every measurement - the comparisons showed that the agreement between the SCIAMACHY ozone profiles and coincident profile measurements with several different instruments and methods is significantly improved when the TH offset is applied. This is another important piece of evidence, that the limb TH after the December 2003 orbit model update are systematically wrong. A paragraph summarizing the main findings of the Brinksma et al. paper was added to section 4.

8) Page 3711, line 9: Can a TH accuracy of better than 250 m be achieved? How realistic is it given the remaining error sources. Are there other limb satellite instruments, which achieve this accuracy?

Another good point! I believe, that pointing accuracies of 250 m and better will be difficult to achieve with knee-type pointing retrievals, e.g., with TRUE. And even, if TRUE pointing retrievals were accurate to within 250 m this would be extremely difficult to prove. In other words, the statement, that TRUE is accurate within 250 m is not verifiable. However, achieving pointing accuracies of a few hundred meters should be possible by improving the orbit propagator models that control the limb mirror positions and also provide the tangent heights for each individual limb spectrum. In the case of OSIRIS, the analysis of in-flight star-tracker data showed that the limb pointing is accurate to within about (15 seconds of arc (corresponding to a tangent height difference of about 200 m) over extended periods. At other times, however, the nominal accuracy of 1.2 minutes of arc is just fulfilled. Although the referee has a valid point by asking whether a pointing accuracy of 250 m is achievable, our statement was more based on a science perspective that puts strong limitations on the maximum measurement error that makes scientific applications of the ozone profile retrievals possible. If the total measurement error exceeds 10 - 15 % then the scientific use of the profiles is highly questionable for most applications. Mis-pointing is of course not the only, but one of several important sources of systematic and random errors that affect the ozone profile retrievals. Therefore, we believe that from a science perspective a 5 % retrieval error contribution due to pointing errors is desirable.

9) Page 3710, line 23, typo: '1.31 km' –> '1.13 km'

Thanks, corrected.

We wish to thank all three referees for really good and constructive reviews and hope that our changes have improved the manuscript.

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