Author response to Reviewer Comments for: "MIPAS-STR measurements in the arctic UTLS in winter/spring 2010: instrument characterization, retrieval and validation"

Atmos. Meas. Tech. Discuss., 4, 7035-7108, 2011
W. Woiwode et al.

We would like to sincerely thank the two reviewers for helpful and concise comments which will help improving our article. In the following, we address the comments of both reviewers. Page and line numbers refer to the unrevised manuscript (*amtd-4-7035-2011-print.pdf*). We provide in each case the original referee comment (bold italic letters) followed by our response.

Summary of General issues

Referee #1 suggests shortening the publication (in particular sect. 2, 3 and 5), since several points were already addressed in the literature in different context. Referee #2 recommends ensuring that all figures are legible when printed out at page size and wishes the effects of considerable overlaying O_3 on the retrieved O_3 below flight path to be addressed.

For technical reasons we begin with answering the comments of referee #2 and will then come to the comments of referee #1. Since we will follow the recommendation of referee #1 and will shorten several sections, some of the minor corrections of referee #2 might then become obsolete.

Response to Referee #2

General

Figures: Ensure that all the figures are legible when printed out at the actual page size.
We will pay attention that all figures are clearly readable at page size (especially Fig. 14 and 15).

P7062/P12-17: The issue of not scanning above the flight path seems rather important and I would have expected to see a detailed simulation of a case where there is considerable overlaying stratospheric O3 above the measurement scan and its effect on the retrieved O3 below. This is listed as a 'seconday error' in section 5.5 but no convincing argument is given as to why this effect can be ignored.
We would like to mention that (i) in each vertical scan several upward viewing geometries are included, allowing for the reconstruction of the netto spectral contribution from above the flight path (i.e spectrum of the column) and to a limited extent also vertically resolved information of this region. (ii) We remark that the in-situ comparison for O_3 along flight path (Fig. 15b) indicates very good agreement along the entire flight, whereas very different air-masses were passed (i.e. vortex air and extra-vortex air), cf. Fig. 8. This is at least a hint that here no further dominant error is hidden in the results.

However, we agree that this point is important and address this issue with additional simulations discussed in the following.

We propose adding after P7062/L16: "…also vertical information. The low impact of variable ozone above the flight path on the vertically resolved region of the retrieval for this gas below and around flight altitude (which is considered in the following sections) is shown in Fig. 11. (*other Figure numbers to be changed*). Forward calculations were carried out based on two ozone profiles with identical mixing ratios below 20 km and significantly different mixing ratios above. The corresponding forward spectra were retrieved using the same indicated initial guess and a-priori profile, resulting in nearly identical profiles in the vertically resolved region of this limb scan between 8.5 and 17.5 km.

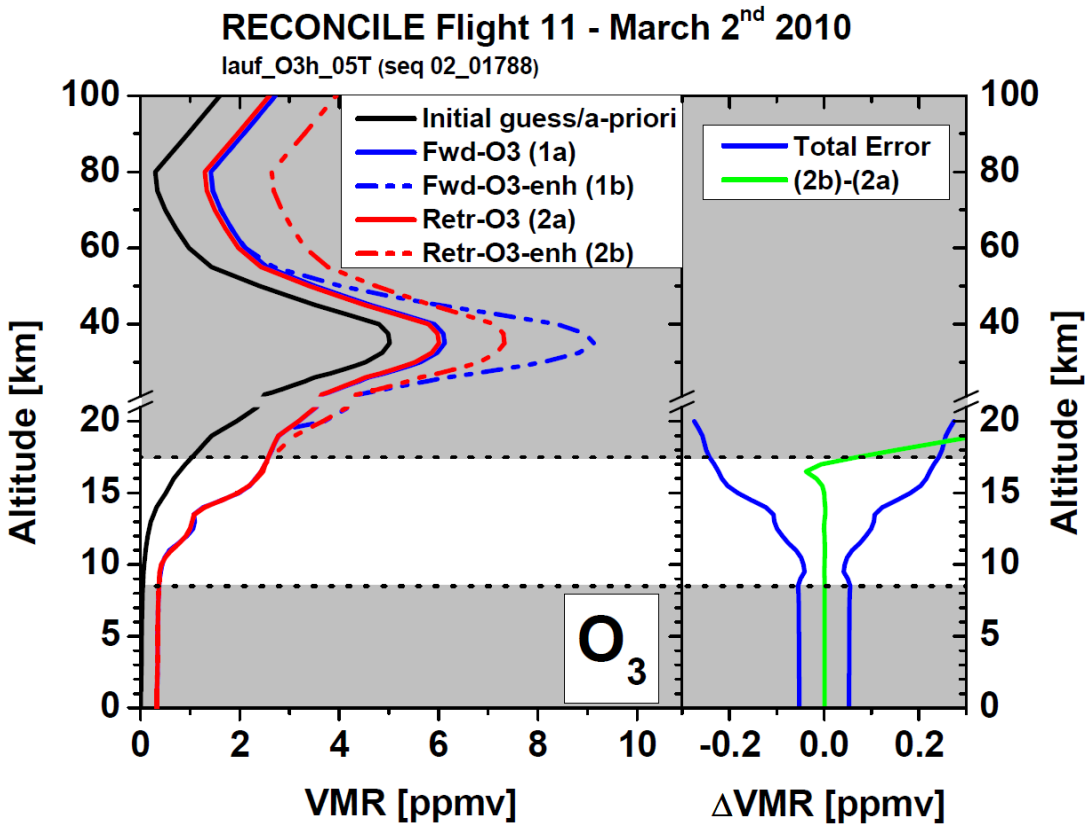

Fig. 11: Retrieval simulations for different ozone maxima above the flight path (flight altitude: 16.7 km). Left panel: Profile Fwd-O3 (1a), derived from nominal processing of scan 02_01788, and Fwd-O3-enh (1b) with enhanced ozone above flight path were applied for forward calculations based on the viewing geometries, measurement noise and atmospheric conditions of scan 02_01788. The resulting forward spectra were retrieved again, yielding profiles Retr-O3 (2a) and Retr-O3-enh (2b). Right panel: Comparison of total error of nominal retrieval result and difference between (2b) and (2a). Regions with vertical resolution of the nominal retrieval result worse than 5 km shaded in grey.

Minor corrections and typos

We thank referee#2 for careful inspection and will consider practically all corrections. For completeness we discuss the following corrections in this context:

P7038/L24: APE-GAIA => expand the acronym

Done. (Airborne Polar Experiment - Geophysica Aircraft In Antarctica).

P7038/L28: MARSCHALS => expand the acronym

Done. (Millimetre-wave Airborne Receiver for Spectroscopic CHaracterisation of Atmospheric Limb-Sounding)

P7043/P6: deep space => cold space

See comments of referee #1: “deep space” replaced by “zenith view”

P7050/L24: Atlantic western coast

“above the Atlantic western of Scandinavia” replaced by “at the Atlantic western coast of Scandinavia”

P7050/L25: Voight profile

Not found. (spectral line-shape → Voigt profile)

P7049/L12: number independent => number-independent

(P7059/L12) Done. Also corrected throughout paper: “wave number”/”wave-number” replaced by “wavenumber” for consistency.

Response to Referee #1

General

The paper is written like a PhD thesis i.e. giving details which would be OK for a thesis but are not really adapted for a scientific paper. In particular sections 2, 3 and 5 are somewhat tiresome to read since they do not really concentrate on MIPAS-STR giving many details which have already been given in many papers for the “similar” balloon and satellite instruments. I suggest strongly shortening these sections.

We agree that it might be really worth shortening the publication and focusing more the important key aspects in several sections.
However, we would like to mention that this is the first reviewed paper that describes in detail the MIPAS version finally adapted to the Geophyisca, its performance and spectral as well as radiometric calibration. Beside details of the retrieval and validation we also want to give a complete summary of MIPAS-STR and the applied data-processing chain in one publication, allowing for easy comparisons with other instruments and as a reference for further scientific publications.
We thank referee#1 for this useful comment and list our suggested modifications below.

Modifications Section 2

P7039/L25-P7040/L1: *"Since … here."* → "Here we give a short updated summary of the instrument characteristics."

P7040/L3-4*: "…around 3000 km. The typical airspeed … stratospheric altitudes is about 700 to 750 km* h^{-1}*."* → "…around 3000 km at a typical airspeed of 700 to 750 km h^{-1}."

P7040/L9-11: *"Basically … instrument-control electronics."* → "The instrument is set up by the optics module, including the scan-mirror, telescope, interferometer and detector unit, and the electronics module, including the data-processing and instrument-control electronics."

P7040/L18-L27: *"The vertical FOV-extension … uncertainties."* → "The vertical FOV weighting function is characterized by calibration measurements on ground to minimize uncertainties in the retrievals. Instrumental line shape (ILS) related effects on the retrieval are considered by a theoretical model (Stiller et al., 2000)."
Therefore we replaced P7062/L22-23: *"The minor importance … in Sect. 2."* → "FOV and ILS related effects have been shown to be of minor importance in radiative modelling for the comparable instrument MIPAS-ENVISAT by Stiller et al. (2002)."

P7041/L22-28: *"The electronics … (see http://www.iridium.com/default.aspx)."* → "The electronics module consists of a hierarchic transputer network with a PC-based computer as top system. Subsystems are the interferometer electronics, the line-of-sight (LOS) electronics and the housekeeping/auxiliary electronics. The system is designed for fully automatic operation during flight, but however can be accessed and commanded via an Iridium satellite link (see http://www.iridium.com/default.aspx) during flight."

P7042/L1-6: *"Since … control loop."* → "Since the measurements are performed at fixed tangent altitudes/elevation angles, an accurate line-of-sight (LOS) stabilization is required for compensating roll-variations of the aircraft. The development and verification of the LOS stabilization of MIPAS-STR is described by Keim (2002)."

P7043/L7-14: *"The standard … 45 km."* → "The standard sequence includes limb-viewing geometries with tangent altitudes between 5 km and flight altitude (vertical spacing mainly 1 km or 1.5 km) and comprehensive upward sampling. For a typical flight altitude of 18 km, one full limb scan including calibration measurements takes about 3.8 min, corresponding to a flight path of approximately 45 km."

P7043/L16, L17: "corresponding to an" →omitted (2x)

Modifications Section 3

P7044/L2-21: *"The spectral and radiometric … in more detail."* → replaced by:
"Aspects of the spectral and radiometric calibration procedure are e.g. described in Höpfner et al. (2000) and Keim (2002) and are related to the procedure for the balloon-borne

instrument MIPAS-B2 (Friedl-Vallon et al., 2004). Here we give a summary of the full calibration cycle specific to MIPAS-STR (compare Fig. 4)."

P7044/L24-P7045/L2: *"After determination, …calibration steps."* → omitted

P7045/L8-11: *"Furthermore, the ….is slightly different."* →"The latter three steps are carried out separately for each interferometer scan direction (forward/backward sweeps are carried out alternatingly), since the data-acquisition is slightly different."

P7045/L17-23: *"Accordingly, … measured at the detector."* → "The effects of nonlinearity are deduced and corrected from the higher order artefacts in blackbody spectra from interferograms without digital filtering data reduction as a function of the corresponding DC-level measured at the detector."

P7045/L24-25: *"In the case of MIPAS-STR … is carried out."* → omitted

P7046/L1-2: *"… quantified by the minimization of the corresponding artefacts according to Kleinert (2006)."* → "… quantified by the minimization of the observed artefacts." (Kleinert (2006) already mentioned above)

P7046/L5-9: *"Although the … calibration valid."* →omitted

P7046/L22-24: *"Since the beamsplitter emission … cannot be applied here."* →omitted

P7047/L3-4: "*This step is applicable, … comparably weak."* → omitted

P7047/L20-21: *"(negative and positive elevation angles)"* → omitted

P7048/L5-13: *"For this step … filter function."* → replaced by "For this purpose, a preliminary calibration is applied to the zenith view spectra, including a line fitting step without radiative transfer and a first determination of the gain function from the blackbody measurements."

P7048 L18/19: Eq. (2) → Eq. (1)

P7048 L20-22: *"whereas c(ν) represents the final radiative gain function, BB(ν) the blackbody spectrum, U(ν) the instrumental offset spectrum, B(ν,T) the Planck function of the temperature T and e(ν) the emissivity of the blackbody."* → "whereas ν stands for the spectral position, c(ν) for the radiative gain function, BB(ν) for the blackbody spectrum, U(ν) for the instrumental offset spectrum, B(ν,T) for the Planck function of the temperature T and e(ν) for the emissivity of the blackbody."

P7048 L22-24: *"With the knowledge of the precise instrumental offset and the radiative gain function, the atmospheric spectra are calibrated according to Eq. (1)."* → "With the knowledge of the instrumental offset and the radiative gain function, the atmospheric spectra are calibrated according to the two-point calibration approach:

$$S(\nu) = \frac{A(\nu) - U(\nu)}{c(\nu)} \qquad (2)$$

whereas S(ν) represents the calibrated atmospheric spectrum and A(ν) the atmospheric raw spectrum."

Modifications Section 4

P7050/L13-14: *"The altitude distribution … aircraft position."* →omitted

Modifications Section 5

P7051/L8-20: *"… retrieved profile. … is applied:"* → "… retrieved profile. Various atmospheric aspects of radiative transfer and instrumental aspects are supported, including non-spherical ray-tracing, refraction, FOV and ILS. Spectral lines of target gases are modelled using the Voigt profile, and for species with unresolved signatures, available cross-section data is applied. Utilizing the analytical derivatives provided by KOPRA, the inversion algorithm KOPRAFIT allows for the fitting of the full set of observations of one scan in many microwindows simultaneously. For the inversion of atmospheric parameter profiles in this context, Gauss-Newton iteration subjected to Tikhonov-Phillips regularization (Tikhonov, 1963; Phillips, 2003) is applied:"

P7052/L1-9: *"(e.g Steck, 2002) and the regularization … and retrieved spectra."* → "and the regularization strength is adjusted by the regularization parameter $\boldsymbol{\gamma}$. An advantage of the applied Tikhonov-Phillips smoothing constraint is the fact, that systematic biases with respect to absolute values of the target parameters are avoided rather than using a climatological constraint (e.g. Steck, 2002). The regularization parameters for the target parameters temperature, trace gases and background-continuum are optimised individually, avoiding oscillations in the results and considering the residuals between the measured and retrieved spectra."

P7053/L3-5: *"… mid-infrared limb-emission spectra. Typical spectral signatures of PSC constituents allow for the classification of PSC types (e.g Höpfner et al., 2006). Also cirrus ..."* → "… mid-infrared limb-emission spectra (e.g Höpfner et al., 2006). Also cirrus …"

P7053/L17-P7054/L2: *"… limiting factors. … observation geometries."* → "… limiting factors. Candidates are here e.g. the broad family of the halocarbons (e.g. Fabian and Borchers, 1981) and probably also aliphatic and aromatic hydrocarbons. Although many species alone give rise to only weak signatures below or close to the NESR of MIPAS-STR, the net-effect accumulated by many different species can significantly affect the observations."

P7054/L3-5: *"The third aspect … decreasing altitude."* → "The third aspect results from the significantly increasing pressure broadening of spectral lines observed with decreasing altitude in the UTLS region."

P7054/L8: *"of the effects"* → omitted

P7054/L15: *"on the spectral baseline within a microwindow"* → omitted

P7054/L24-26: *"Although … completely."* → omitted

P7055/L7-11: "*Taking this into … (Sect. 6)."* →omitted

P7055/L20-23: *"Such effects … stratospheric altitudes."* → omitted

P7055/L27-P7056/L3: *"As pointed out … quantified by retrievals."* → "As pointed out in Sect. 2, only a constant absolute offset between the reference system of the AHRS and the instruments LOS has to be quantified by retrievals."

P7056/L7: *"resulting in one single parameter per flight"* →omitted.

P7056/L15-29: *"Since … stratosphere."* →omitted

P7057/L8-9: *"as the temperature retrieval"* →omitted

P7057/L12-15: *"In contrast … temperatures."* → omitted

P7057/L20-24: *"Using … are retrieved."* → "Using previously fitted fixed profiles of significantly interfering species rather than climatological profiles allows for an improved modelling, which is especially important when spectra of air-masses from different origins (e.g. vortex and extra-vortex air) are retrieved within single limb scans."

P7057/L27-28: *"(depending on … selected microwindows)"* → omitted

P7057/L29-P7058/L4: "*Hence … modelling.*" → omitted

P7058/L5-10: *"Following … profiles."* → omitted

P7059/L1-3: *"The regularization … profiles."* →omitted

P7059/L14-15: *"As mentioned before … if possible."* → omitted

P7059/L20-29: *"Regularization … flight."* → "Regularization is applied to the retrieval parameters temperature, trace gases and background continuum and the regularization parameters are kept constant for all limb sequences of a flight."

P7060/L1-5: *"Pressure … account."* → "Pressure profiles for all retrievals and temperature profiles for the LOS-retrieval are interpolated from the ECMWF analysis at T106 resolution."

P7061/L21-22: *"since in the retrieval constant atmospheric conditions are assumed for single limb scans."* → omitted

P7063/L5-17: *"As described … results."* → " As described in Rodgers (2000), another relevant error may the smoothing error. Since this error is highly dependent on the choice of the estimate of the true ensemble covariance used for calculation (i.e. a climatological covariance matrix), we regard the retrieval result as an estimate of the smoothed version of the state and show the vertical resolution instead."

P7063/L28-P7064/L2: *"As can … appropriate."* → omitted

P7064/L7-9: *"Hence … AHRS."* → omitted

P7064/L23-24: *"by the root of the square sum"* → omitted

P7066/L1-2: *"However … Sect. 6."* → omitted

P7066/L14-19: *"In the case … close to 1."* → omitted

P7067/L7: *"… dominating errors."* → "… dominating errors. The relative importance of the different errors can vary from scan to scan, depending on the atmospheric situation, the vertical distribution of the target species, and the sampling geometries."
→Therefore omitted: P7067/L27-P7068/L5: *"For higher … target."*

P7067/L24-27: *"For the … regularization."* → "For the HNO_3-profile shown in Fig. 13, 8.7 DOF are obtained, indicating weak influence of the regularization (for sampling details of the shown scan 02_01788 see Sect. 6.1)."

Modifications Section 6

P7070/L5-7: *"The in-situ result … retrieval."* → omitted

P7071/L8-15: *"Virtually … (von Clarmann, 2003)."* → "Virtually negative mixing ratios below 10 km are a consequence of very low mixing ratios of $ClONO_2$ in the troposphere and can result from spectral interference with other species and smoothing effects of the retrieval."

Modifications Section 7

P7076/L13-22: *"The estimated … spectra."* → "The estimated overall 1σ-errors of the retrieval results are typically below 1 K for temperature and between 10 and 15% for the trace gases in the vertical range spanned by the tangent points and directly above the flight altitude. In this region, characteristic vertical resolutions of 1 to 2 km are obtained, allowing for the identification of narrow vertical structures."

P7076/L23-25: "*The retrieval … between MIPAS-STR and the in-situ instruments, …"* → "The retrieval results show a high degree of consistency with collocated in-situ measurements, …"

P7077/L1-3: " *For temperature … instruments."* → omitted

P7077/L3-5: *"For CFC-11 … extra-vortex air."* → "Higher discrepancies apparent for CFC-11 and CFC-12 around flight altitude are attributed to the observed strong contrasts in the mixing ratios of the CFCs between vortex and extra-vortex air."

P7077/L9-10: *"For … found."* → omitted

P7077/L13-17: *"Small-scale … instruments"* → "Small-scale structures with vertical extensions down to 1 km are resolved and are confirmed by results from the infrared limb-sounder CRISTA-NF."

Other comments

What do the authors mean with: "comprehensive agreement"
P7037/L18 and P7073/L29: *"comprehensive agreement"* → "a high degree of agreement"

Page 7042: ". . .low data age"???
See comments of referee#2 → replaced by "low latency"

I do not like very much "deep space" since in the present case it is not really a deep space measurement. It is then somewhat misleading and I would suggest to replace it by "Zenith view measurement".
Done. Abbreviation *"DS"* replaced by "ZV" accordingly.

Fig. 1 can be suppressed
In our eyes this figure is important, since it represents the version of MIPAS-STR finally deployed onboard the Geophyisca.

Fig. 5 is not really readable: I suggest removing one or 2 spectra.
The 12 km spectrum will be omitted.

The various figures 14 are totally illegible: I suggest either to give a smaller number of examples or to enlarge the figures. - The same remark applies to figures 15.
Figures 14 and 15 shall be printed out at full page size and enlarged, if necessary.