Interactive comment on "Measurement of the Arctic UTLS composition in presence of clouds using millimetre-wave heterodyne spectroscopy"
by E. Castelli et al.
Anonymous Referee #1

The paper describes airborne remote sensing measurements of the UTLS region performed
with the millimetre limb-sounder MARSCHALS near Kiruna in March 2010.
Compared to a previous campaign, the instrument performance has been improved and data from three channels, including additional trace gases are retrieved. Thus, a significant advancement of the system is described which is worth being published. However, some statements in the presentation of the results are rather qualitative and, therefore, require revision before publication. Further, to demonstrate the improvements, spectral fits should be shown from all three bands. A proper data analysis requires also an estimation of the total error budget including a mapping of other instrumental uncertainties apart from the instrumental noise only. At last, the retrieval of extremely low CO values seems rather vague due to some apparent systematic spectral residuum at the position of the CO line. This should be discussed in more detail.

The authors gratefully acknowledge the anonymous reviewer for comments and suggestions. We were happy to follow the reviewer's comments and improve the manuscript as suggested. In particular, in the revised paper we show examples of spectral fits for two scans in each of the three MARSCHALS bands highlighting the differences between good and worse fits.
Regarding the estimation of the total error budget including a mapping of other instrumental uncertainties in these reply we report a breakdown of individual instrumental error components, however, since they are small compared to the to the thermal noise of the receivers we did not add anything in the revised text.
Finally we give particular attention to the analysis of the negative residuum in band D spectra pointed out by the reviewer. We found that this was due to overestimated CH_3Cl profile. Since CH_3Cl interfers with CO, we decided to repeat the whole analysis using a different CH_3Cl profile. Looking for a realistic profile we choose to use a CH_3Cl profile extracted from Aura/MLS data on the 10 March 2010 at polar regions.
In this new analysis the residuum from band D spectra was removed and higher CO values were found.
According to this findings we updated the figures and tables on the revised paper. The new approach has no impact on the majority of the analysis. Very small changes are found in chisquare values (Fig.3), HNO_3 retrievals (Fig.8a and 16d of the discussion paper) and scalar quantities reported in Table 4 (where we correct also some typos) for this reason no changes were made into the text. Major differences were found in CO analysis (Fig.s 12 and 13 of the discussion paper) and for this reason the section on CO results was updated.
The answers to referee's specific comments and technical comments are given in blue below each of the reviewer's comment.

Specific comments:
P3130,L21: 'The performance of the retrieval are demonstrated from the results of data processing of MARSCHALS, deployed in the 2010 Arctic campaign with the M-55 Geophysica as an airborne simulator of the millimetre-wave limb-sounder proposed for the ESA Earth Explorer 7 candidate Core Mission PREMIER (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation).'

This sentence of the abstract is not very clear and does not really fit to the preceding text. It should be improved. Further, throughout the paper references to PREMIER should be updated with respect to the results of the selection process for EE7.

In the abstract, line 21 p. 3130, we replaced:
“ The performance of the retrieval are demonstrated from the results of data processing of MARSCHALS, deployed in the 2010 Arctic campaign with the M-55 Geophysica as an airborne simulator of the millimetre-wave limb-sounder proposed for the ESA Earth Explorer 7 candidate Core Mission PREMIER”
with:
“The results of MARSCHALS data analysis contributed to demonstrate the scientific relevance and technical feasibility of millimetre-wave limb-sounding of the UTLS proposed for the ESA Earth Explorer 7 candidate Core Mission PREMIER. PREMIER was not selected at the end of the Earth Explorer 7 evaluation process, but it is still being considered for future launch opportunities.”
Furthermore, we have updated the references to PREMIER according to the results of the selection process for EE7:
in line 18 p. 3132 we replaced:
“The primary scientific objective of the PREMIER mission is to gain a better understanding of the interaction processes linking atmospheric chemistry and dynamics with climate. This will imply the investigation of distribution and transport of trace gases and of the radiative effects of water vapour and clouds in the mid to upper troposphere and lower stratosphere. PREMIER will achieve this through the combined observations by two limb-sounders: one of which will be operating in the thermal infrared (InfraRed Limb Sounder, IRLS), the other in the sub-millimetre-wave region (Millimetre-Wave Limb Sounder (MWLS) a.k.a. Stratosphere-Troposphere Exchange and Climate Monitor Radiometer, STEAM-R)“
with:
“The primary scientific objective of the PREMIER mission was to gain a better understanding of the interaction processes linking atmospheric chemistry and dynamics with climate. This imply the investigation of distribution and transport of trace gases and of the radiative effects of water vapour and clouds in the mid to upper troposphere and lower stratosphere. This can be achieved through the combined observations by two limb-sounders: one of which operating in the thermal infrared (InfraRed Limb Sounder, IRLS), the other in the sub-millimetre-wave region (Millimetre-Wave Limb Sounder (MWLS) a.k.a. Stratosphere-Troposphere Exchange and Climate Monitor Radiometer, STEAM-R)“
in line 3 p. 3140, we replaced:
"The aim of the PREMIER mission is to quantify the processes that control the composition and structure of the UTLS."
with:
"The aim of the PREMIER mission was to quantify the processes that control the composition and structure of the UTLS."
In the “Conclusions” section in line 16 p.3154 we replaced:
"The possibility to retrieve CO profile from millimetre-wave spectra was thoroughly explored, since in the PREMIER mission the millimetre-wave sensor STEAM-R will be the only instrument able to provide CO measurements."
with:
"The possibility to retrieve CO profile from millimetre-wave spectra was thoroughly explored, since in the PREMIER mission the millimetre-wave sensor STEAM-R was the only instrument able to provide CO measurements."
and in line 18 of the same page we replaced:

"As an air-borne demonstrator for the STEAM-R millimetre-wave limb sounder, the MARSCHALS instrument widely demonstrated its capability in this flight. The testing and demonstration of the inverse modelling of MARSCHALS measurements provided crucial information in the perspective of future deployment of millimetre-wave radiometers from space, like the STEAM-R instrument part of the PREMIER mission. "
with:
"As an air-borne demonstrator for the STEAM-R millimetre-wave limb sounder, the MARSCHALS instrument widely demonstrated its capability in this flight. The testing and demonstration of the inverse modelling of MARSCHALS measurements provided crucial information in the perspective of future deployment of millimetre-wave radiometers from space, like the STEAM-R instrument."

P3134L6: 'The limb of the atmosphere is sampled through an open aperture in the starboard side of the Geophysica aircraft at angles equivalent to 1 km tangent point steps. A single scan of 28 measurements starts just below ground level and reaches up to just above platform altitude and includes an additional space view at 20 above horizontal.
This is somehow contradictory to what is shown further below in the manuscript where the tangent point sampling seems not to be uniform. Could you clarify this in the text? Further, could you specify the FOV width and how it relates to the tangent point sampling?

To understand the observed non-uniformity of tangent point sampling of MARSCHALS, a more detailed explanation of the working of the antenna pointing system is required. Most importantly, it important to know that the antenna pointing system of MARSCHAL is using view angles as its internal reference and not tangent altitudes. At the outset of the process is a table of nominal scan angles, which is written to an EPROM and used by the instrument in flight as a target reference. This list of reference view angles has been calculated to produce an equally spaced grid of tangent point altitudes of 1km step size. These calculations are based on a 20km flight altitude, so neighbouring tangent points will already differ if the aircraft is not flying perfectly level. To compensate for that, the scan range is generously extended at either end by ~1 degree.
On top of that, there are various known – and unavoidable – biases, which mean that the pointing system has to be regularly reset during flight. If during these resets the aircraft is not flying perfectly level, the following scan angle range can be offset with respect to the nominal scan angles. This again is mostly negated by the safety margins in the nominal scan angle range, but it means that the tangent point altitudes of neighbouring scans are not all aligned.
In absolute terms this is not critical, because a post-flight pointing reanalysis allows us to calculate the offset between the perceived horizon of the gyro and the airframe horizon from the aircraft flight attitude records. Based on this we can then calculate the true altitudes of the tangent points. There are however some biases that remain unknown, i.e. a non-constant offset between the alignment of the airframe and the instrument frame (which is mounted on vibration-isolating springs). For this reason, a pointing bias has to be retrieved in the Level 2 processing.
Figure 1 Reply illustrates the pointing behaviour, and shows why the tangent point altitudes (expressed in kilometres) are not the same for consecutive scans.
Another indication that the reconstructed pointing knowledge is accurate is shown in Fig. 2 Reply. This shows individual frame of the Optical Cloud Monitor, which is mounted fixed to the MARSCHALS frame. The pointing data from MARSCHALS is used to collate the individual frames together, corrected for the aircraft roll. This results in a smooth cloud surface, indicating the accuracy of the attitude knowledge of MARSCHALS.

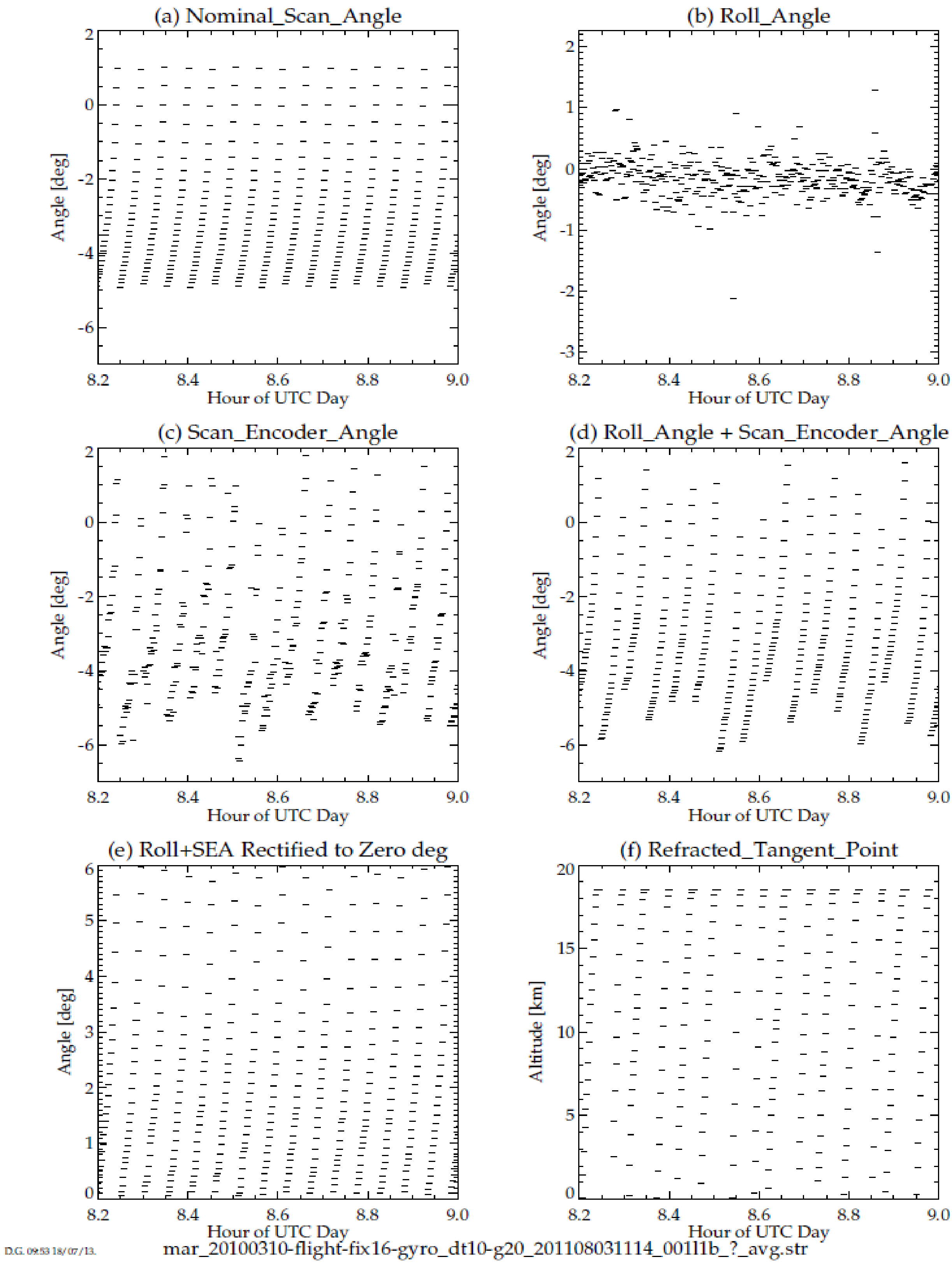

Figure 1 Reply: Illustration of pointing behaviour. The nominal scan angles (a) are fixed. The aircraft roll (b) is corrected for in the scan encoder angle (c). Adding scan encoder angle to the roll equals to the actual elevation angles (d). Because the pointing update doesn't work well when the aircraft is unstable, the actual scans are offset w.r.t. each other. Panel (e) shows a rectified version of panel (d) where all the scans are shuffled up/down to start at Zero; here the alignment is good. Because the nominal angle spacing isn't applied to the altitude range it was computed for, the actual tangent point altitudes (f) don't have the same spacing from one scan to then next. The absolute value of the tangent altitudes however is well known from post-flight analysis of the aircraft and gyro roll data

records.

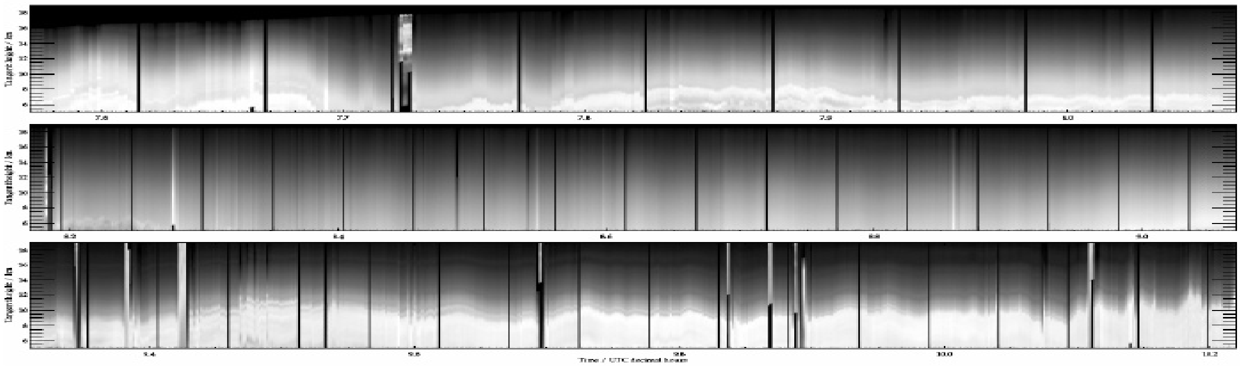

Figure 2 Reply: Another indication that he pointing knowledge is good is this reconstruction of individual frames from the optical cloud monitor. Using our roll angle data, we have collated the individual pictures of the camera that is mounted fix to the airframe, and obtain a smooth cloud top surface.

In the revised text we clarify this in line 10 p . 3134 after " … space view at 20 above horizontal." we added a new paragraph:
" An active antenna control loop with a gyro as its reference stabilises the antenna to within fractions of a degree stability (+/-0.01 deg when the absolute roll angle rate of change is contained within the +/-0.63 deg/s design range). Because of various biases in the antenna knowledge (i.e. non-reproducibility of the alignment w.r.t. the airframe, temporal bias in the gyro record due as a function of geographic latitude, etc.) the antenna system has to be regularly reset to horizontal. If during these resets the aircraft is not flying level – which it quite often does not – then these updates can lead to the following scan can be offset in angle range compared to the nominal scan angles. This is mostly compensated by the safety margin in the nominal scan angle range, and it is not a problem for the data analysis because the absolute value of the tangent point altitude can be accurately reconstructed post-flight, but it implies that in reality tangent points of neighbouring scans will be at slightly different altitudes."

P3144L4: 'Each MARSCHALS scan was analysed individually, retrieving four scalar instrumental parameters (gain, offset, pointing bias angle and frequency shift) along with vertical 5 distributions of temperature, water, ozone, nitric acid, nitrous oxide, carbon monoxide and extinction coefficient.'
How strong is the dependence between offset, gain on the one side and extinction coefficient on the other? Can these quantities well be distinguished by the retrieval. Which constraint has been used for the continuum profile retrieval?

Following the reviewer suggestion, we evaluated the correlations between offset and gain on one side and external continuum on the other using the Variance Covariance Matrix of the retrieval.
In Fig. 3 Reply we report the average correlations (solid lines, and relative standard deviations, dashed lines) between external continuum retrieved at different altitudes and gain and offset in band B, C and D. We performed the averages over all scans of each bands.
In band B and D no correlation is present between external continuum and offset and gain values (correlation values are always lower than +/- 0.25 for both gain and offset). In band C we found no correlation between the retrieved external continuum and the gain (maximum value lower than –0.25 at 18 km) while low anti-correlation is found between the external continuum retrieved at the highest point in the retrieval grid (e.g. 18 km) and the offset. In this case, the average anti-correlation value is of the order of -0.6.

Since the correlations are generally low or very low, we can conclude that the retrieval procedure is able to distinguish between different contributions.
This is also highlighted by the fact that the retrieved gain and the offset values are quite similar in all bands with values close to the expected ones (0K for offset and 1.0 for the gain, see Table 4). Since we did not find any relevant correlation between these parameters, we did not add any consideration about that in the revised text.

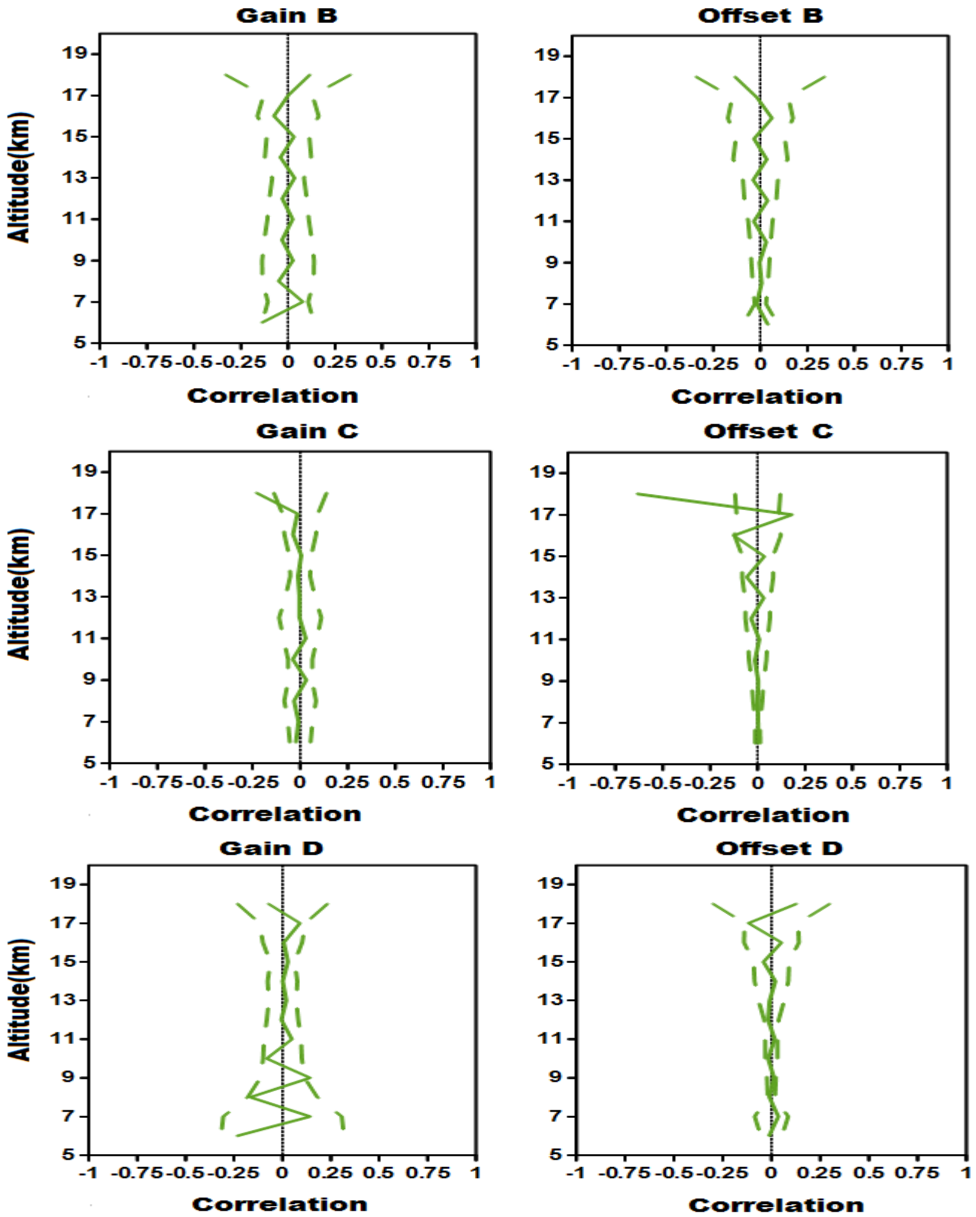

Figure 3 reply: Average correlations (solid lines) and standard deviations (dashed lines) between external continuum retrieved at different altitudes and gain and offset in band B, C and D.

Regarding the continuum retrieval, the a priori error used in the analysis is set at 0.2 10^{27} cm^2 for all the retrieved altitudes. In the revised text, we added this information in line 21 p. 3144 after "... 0.2.", in particular we added: "The a priori error on the external continuum was set to a constant value of 0.2 10^{27} cm^2.

P3144L5: How have the profiles above the highest grid point been handled? (e.g. scaled with the highest point)

The profiles above and below the highest and lowest retrieved grid altitudes have been extrapolated following the shape of the initial profiles (scaled with the highest and the lowest retrieved point respectively). In order to clarify this in line 8 p. 3144 at the end of the paragraph we added :" The profiles above and below the highest and lowest retrieved grid points have been extrapolated following the shape of the initial profiles (scaled with the highest and the lowest retrieved point respectively".

P3146L10: In addition to the chi-square I strongly recommend to show examples of spectral fits with residuals for all three bands, on the one hand for a case with good chi2 and on the other for those with larger chi2. I think this would be needed to show the quality of the observations and to judge whether other instrumental effects, like channeling might be present.

Following the reviewer's suggestion, in the revised text we added one figure (new Fig.4) where we show the average residuum together with the corresponding standard deviation and the average noise level for two scans in each band, one corresponding to a case with good χ^2 values and one corresponding to bad χ^2 values (scan 22 and 49 in band B, scans 12 and 51 in band C and scans 29 and 47 in band D). As can be noticed from the figure, cases corresponding to higher χ^2 values had standard deviations of the residuum higher than the noise level. The average residuum was lower than the noise level and did not show any particular features.
In the revised text (line 20 p. 3146) we added:
" In order to better evaluate the retrieval performances, in Fig.4 we show the average residuum together with corresponding standard deviation and average noise level for two scans in each MARSCHALS band:
For one scan we obtained good χ^2 values (scan 22 in band B, scan 12 in band C and scan 29 in band D, residuum plotted in blue) while for the other we had worse performances (scan 49 in band B, scan 51 in band C and scan 47 in band D, plotted in red). As can be noticed, worst χ^2 values were obtained when the residuum standard deviation was higher than the noise level. In general no particular feature can be seen in the residuum. The residuum behaviour highlights the quality of MARSCHALS measurements and retrieval results."
Then we added the Figure (new Fig.4) and corresponding caption:

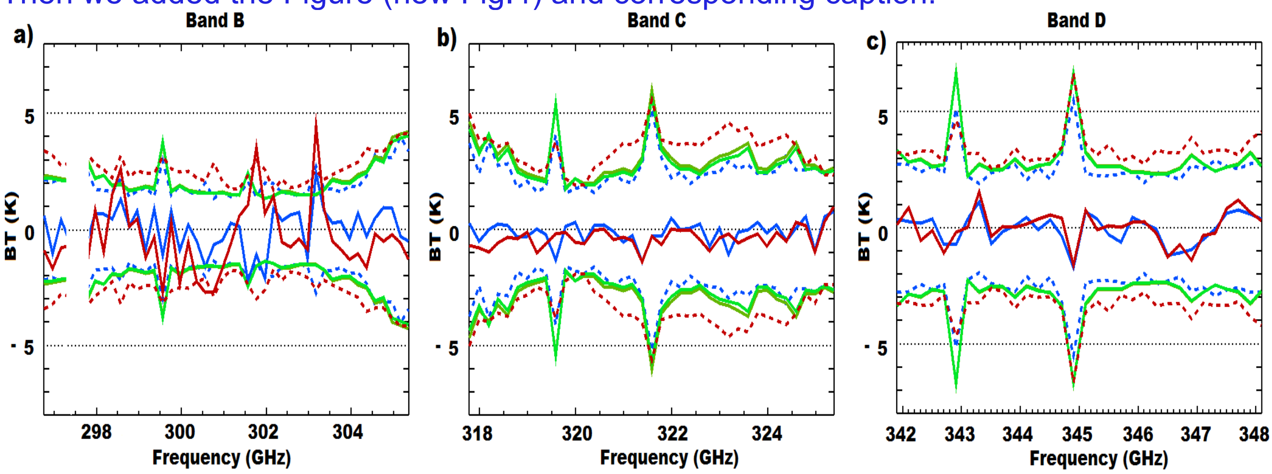

Fig. 4: Average noise level (green), average residuum (solid lines, blue for the best and red for the worse scan) and corresponding standard deviations (dashed lines) for: (a) scans 22 blue and 49 red in band B, (b) scans 12 in blue and 51 in red in band C, (c) scans 29 in blue and 47 in red for band D.

Chapter 4.3: Only instrumental noise errors are shown. However, I miss an estimation of the total instrumental error budget taking into account the uncertainties due to instrument characterization (e.g. FOV knowledge, calibration, instrumental line shape, baseline effects, pointing uncertainty/stability) At least for single profiles it would be interesting to see how those uncertainties relate to the noise error.

Most of the instrument parameters have been measured by RAL in the laboratory. They are therefore well known and small compared to the thermal noise of the receivers. Here is a breakdown of the individual components:

FOV knowledge:

When last characterised as part of UAMS, we estimated a ripple of 0.1dB p/p on the antenna pattern cuts so I think we can ascribe an error of ±0.05dB to the ACAPs. Angular resolution is 0.01 degree, so we can assume that the boresight precision is ±0.01 degree. ACAP noise floors are:

Band B: -44.5dB
Band C: -49.4dB
Band D: -52.4dB

Instrumental line shape:

The spectral response functions of the instrument have been measured in the laboratory. Due to the nature of the experiment it is difficult to put a number on the accuracy of the measurements, but we have repeated the runs several times with conclusive repeatability. We therefore consider the spectral response to be a known parameter (certainly compared to the instrument noise).

Calibration: / Baseline effects:

These two points are in fact linked. Due to the open instrument designs with no windows there are no baseline effects apparent in the spectrum due to standing waves in the quasi-optical system. More precisely, baseline effects are at a level below the measurement noise. There is evidence to back that: After the UAMS upgrade when the noise performance of the Band B receiver was improved significantly, evidence of a standing wave in the spectra started to appear. We also observed a calibration error of ~2K on the space views (i.e. there was a negative offset of ~2K in Brightness Temperature for the +20 degree space view, which is used as a reference and accurately modelled in the radiative transfer calculations because of the marginal contribution from trace gas lines). This indicated a standing wave terminating at the cold load target. We have consequentially replaced the old calibration target with a new one having improved black body performance, and both the standing waves and the calibration error have disappeared, so that we are once again in a situation where these errors are marginal.

Pointing uncertainty/Stability:

The pointing stability is very good (+/- 0.01 deg when the absolute roll angle rate of change is contained within the +/-0.63 deg/s design range, see Fig. 4 Reply). We do observe a pointing offset error on each scan from a combination of an error during the pointing update and some biases that have to be determined from a comparison of aircraft ant gyro roll-angle date (see also answer to question P3134L6). This allows us to accurately calculate the true tangent point altitudes, but it also means that a pointing bias is retrieved in any case. Because pointing is retrieved, there is no error from an initial assumption percolating down to the retrieval results.

Since all these components are small compared to the thermal noise of the receivers we did not add anything in the revised text.

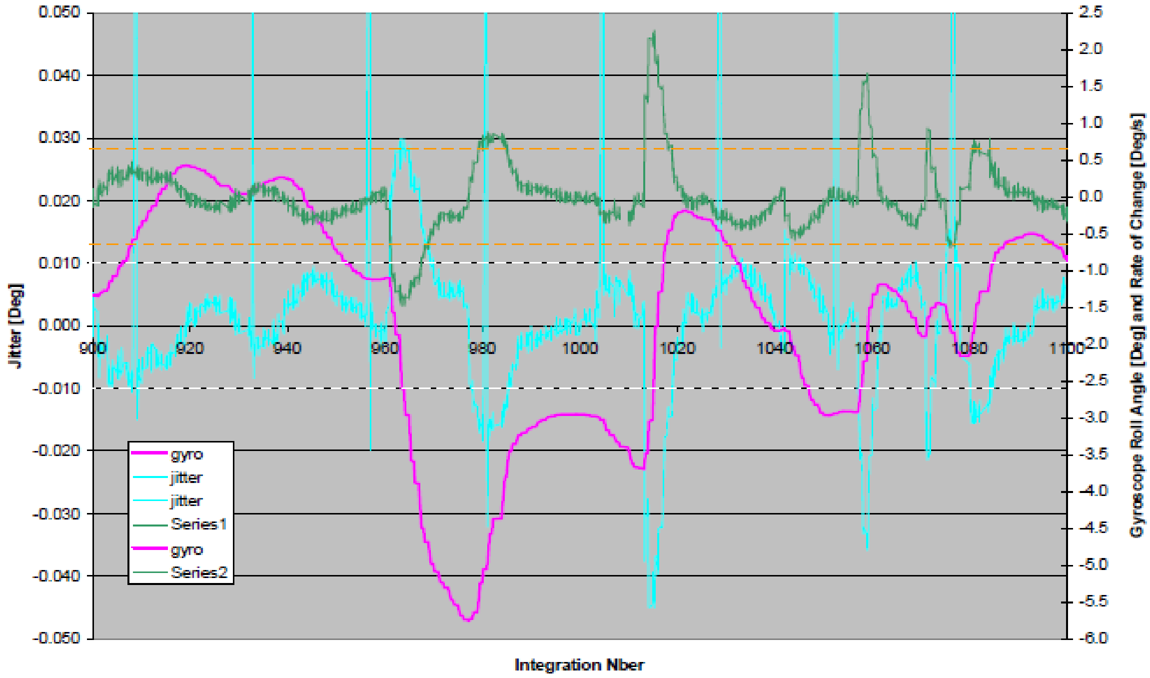

Figure 4 Reply: Analysis of pointing precision during a flight jitter is contained within the required +/- 0.01 deg range (highlighted by the white dashed lines) when the absolute roll angle rate of change is contained within the +/-0.63 deg/s design range (highlighted by the orange dashed lines).

P3148L21: ‘(not shown) show a very good agreement’
What means ‘very good’ here? This should be more quantitative (either as a Figure or quote some numbers).

Following the reviewer's suggestion, in the revised text, in order to support our consideration on the quality of H_2O profiles retrieved from MARSCHALS we included a figure with the comparison of H_2O from MARSCHALS, Aura/MLS and ENVISAT/MIPAS (Fig.7 of the revised paper):

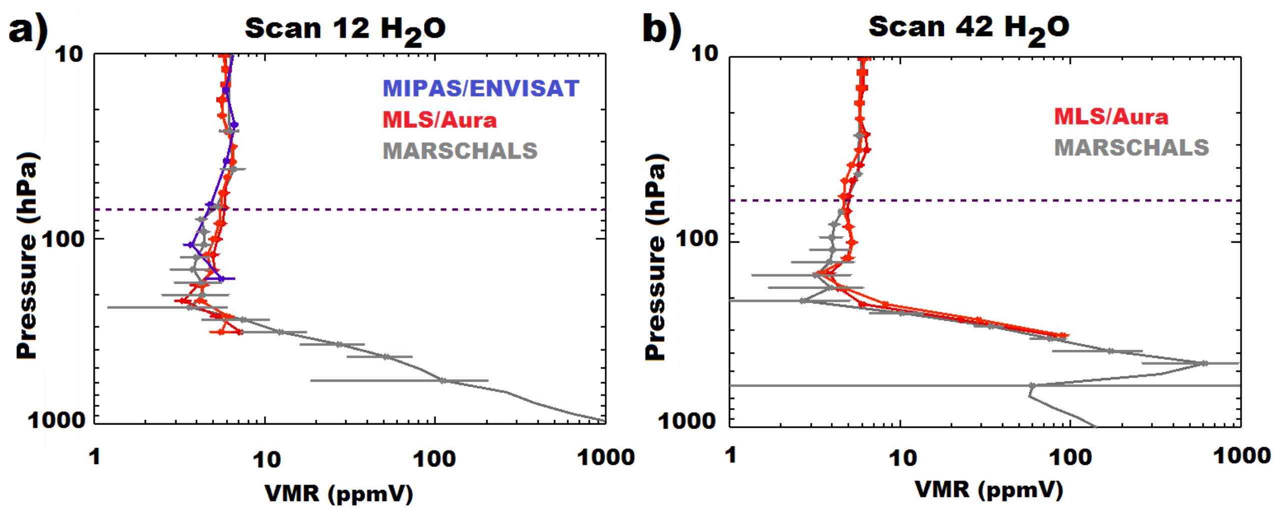

Fig.7:Comparison of H_2O profile retrieved from MARSCHALS scans 12 and 42 (grey) with MIPAS/ ENVISAT (blue) and MLS/Aura (red) H_2O profiles. The horizontal dashed line represents the flight altitude level.

Furthermore, in the revised text, line 20 p. 3148 we replaced :” ... (not shown) show a very good agreement with MLS data especially around the hydropause.” with
“... show a very good agreement with MLS data especially around the hygropause as can

be noticed in Fig.7, where we report an example for MARSCHALS scans 12 and 42."

Fig 7: Could you draw in the flight altitude?

As suggested by the reviewer, in the revised text we drew the flight altitude as a dashed horizontal line in figures 7, 11 and 13 of the original paper. In the corresponding captions we added "The horizontal dashed line represents the flight altitude level."

P3149L23: 'HNO3 data have been compared to MLS/Aura, MIPAS-STR and with MIPAS/ ENVISAT data with good results.'
Please show a figure or at least give more quantitative measures (e.g. % difference at different altitudes).

As for H_2O, following the reviewer's suggestion, in the revised text we added a figure with comparison of HNO_3 profiles from band C and D. Here below, we report Fig.11 of the revised text together with its caption:

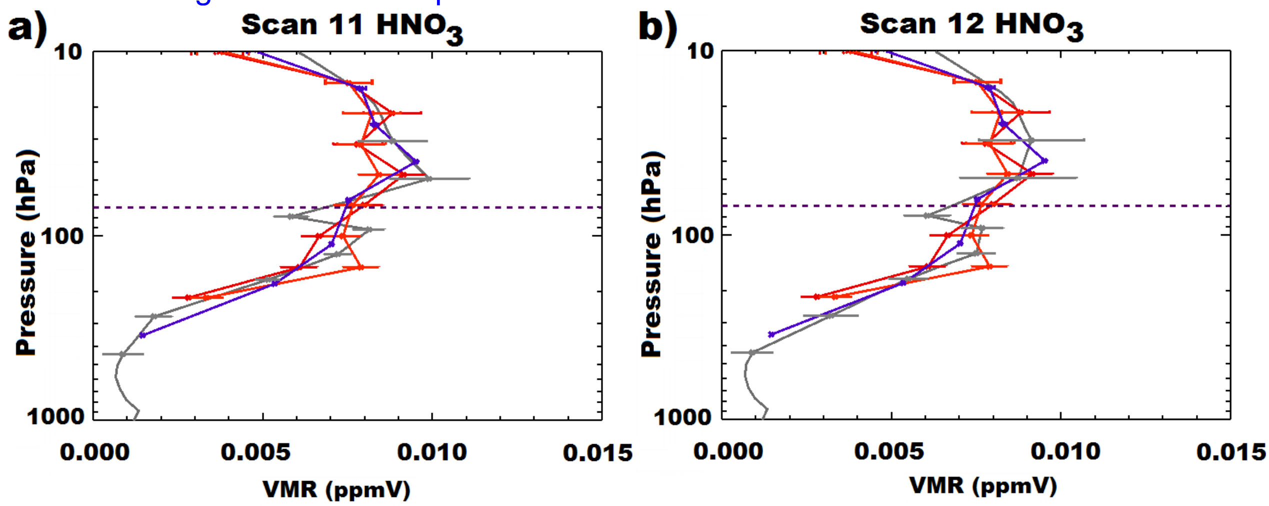

Fig.11: Comparison of HNO_3 profiles retrieved from MARSCHALS scans 11 and 12 (grey) with MIPAS/ENVISAT (blue) and MLS/Aura (red) HNO_3 profiles. The horizontal dashed line represents the flight altitude level.

Furthermore, in the revised text in line 23 p. 3149 we replaced :
"HNO_3 data have been compared to MLS/Aura, MIPAS-STR and with MIPAS/ ENVISAT data with good results.'"
with:
"An example of the comparison of HNO_3 data retrieved from MARSCHALS for scan 11 in band D and scan 12 in band C and coincident HNO_3 profiles from MLS/Aura, and MIPAS/ENVISAT is reported in Fig.11. In general we can notice a very good agreement.'"

Fig9: This figure is not clear. How do the right and the left panel correspond to each other? (x-axis).

In order to clarify this plot, in the revised text we changed the colorbar and VMR range of Fig. 9a and Fig. 9b according to the ones in Fig. 8a of the discussion paper in order to highlight the correspondence between the two figures. Furthermore, in order to have a better correspondence between the two maps in Fig. 9 we changed the x-axis in both Fig. 9a and 9b.
In Fig. 9a of the discussion paper, we replaced the UTC time with the latitude and

longitude (in degrees) of the instrument during the flight. In Fig. 9b of the original paper, we reported the latitude and longitude of each MLS scan (in the revised text Fig. 9 became Fig. 12).
Furthermore, in the revised text we changed the figure caption accordingly:
"**(a)** HNO_3 values retrieved from MARSCHALS as a function of pressure (from 90 to 200 hPa) and latitude and longitude of the instrument during the flight. The black line corresponds to the 125 hPa level while grey points represent
the MARSCHALS retrieval grid points. **(b)** HNO_3 MLS/Aura values as a function of pressure and latitude, longitude for the scans marked with triangles in Fig. 2a."
Moreover, we changed line 21 p. 3149: "reported in Fig. 9a with respect to pressure and time" with "reported in Fig. 12a with respect to pressure and latitude, longitude of the instrument during the flight".

P3150L14: 'The obtained results can be considered a proof of the robust analysis performed on MARSCHALS data of the PREMIER-Ex flight from Kiruna'
Looking at Fig10a, I would question this robustness. Do you have arguments that any of the structures present in the N2O distribution are real?

As highlighted in Fig. 5 Reply, very few N_2O (in blue) lines are present into MARSCHALS band B near to a strong ozone line (in green). For this reason, the N_2O retrieval from MARSCHALS is a quite hard task. With " The obtained results can be considered a proof of the robust analysis performed on MARSCHALS data of the PREMIER-Ex flight from Kiruna" we intended to highlight the fact that despite of this unfavourable situation we could retrieve N_2O (even if with some oscillations in the profiles).
In order to clarify this in the revised text we changed the statement in line 4 p.3150:
"N_2O profiles can be retrieved only from band B data."
with:
"N_2O profiles can be retrieved only from band B data, where few N_2O spectral lines are present near near one of the ozone lines."
and we added "Since few N_2O spectral lines are present into MARSCHALS band B," in line 13 p. 3150 before "The obtained results ..."

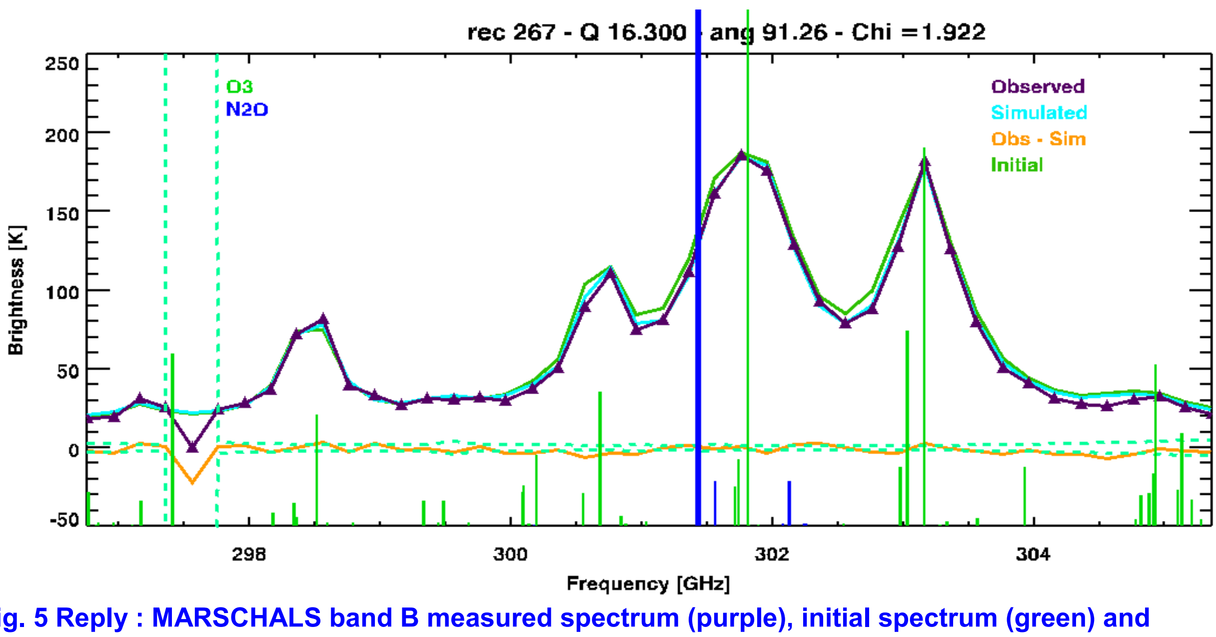

Fig. 5 Reply : MARSCHALS band B measured spectrum (purple), initial spectrum (green) and simulated spectrum (cyan) together with residuum (orange) and noise level (cyan dashed line). Green vertical lines indicate the position of O_3 lines, while the blue vertical lines show the position of N_2O.

Fig13a: How are negative retrieval results handled? Are those just set to zero as the figure indicates?

If the VMR reaches a value that is below zero during the iteration then the applied variation that produced this negative value is divided by two and a new parameter value is computed. We iterate the procedure until the VMR reaches a value greater than zero. In this way, negative VMR values are not allowed however they were not just set to zero.
In order to clarify the way in which the negative VMR are handled into the code, we added:
", while negative VMR values are not allowed into the MARC code."
after the sentence on how we handle profiles above and below the retrieval range in line 5 p.3144.

Fig13c: There is an obvious negative residuum just left of the CO-line? What can be the reason? If it would be an instrumental artefact, it could very well be the reason for the very low CO-values. Does it appear in each fit residuum? Further, the instrumental noise values (which I assume to be 1-sigma values) indicated by the green lines seem to be rather high compared to the residuum.

During the revision of the submitted manuscript, plotting the residuum in order to answer to the reviewer's comment on the fit quality we also further analyse the negative feature left to the CO line that is present in MARSCHALS band D spectra.
We found that it was due to CH_3Cl: the CH_3Cl profile used for the analysis was overestimated at least in the altitude retrieval range.
In the revised paper, in order to address this point, we repeated the analysis using a constant CH_3Cl profile along the flight extracted from the MLS data analysis on the 10 March 2010 in polar region below 20 km. This profile was much lower than the IG2 one. Since CH_3Cl is an interfering species in CO retrievals, the use of a more realistic CH_3Cl profile had an impact on the CO retrieval at altitude levels below 20 km, where very low values were originally found. This new analysis produced higher CO values.
As already pointed out, we updated figures and tables according to the new analysis even if the major part of the results remained unchanged. Some minor changes are visible in Fig. 3a, Fig. 8a, Fig. 16d and Table 4 of the discussion paper. Since these differences were very minor no changes were necessary into the text.
The major differences were found in CO retrievals (Fig. 12a of the discussion paper). For this reason, we update the full Sect.5.6 of the discussion paper that now is as follows:
"CO has only one spectral feature in band D and therefore it can be retrieved from the measurements of that band. Very close to its emission there are few CH_3Cl spectral lines. These lines badly interfere with the CO emission at low altitudes, where the pressure broadening is quite large. As already said in Sect. 4.2, the IG2 profile of CH_3Cl at polar latitudes resulted to be overestimated, producing unrealistic low values of CO at low altitudes. Therefore during the revision process of this paper we have repeated the analysis substituting the IG2 profile with measurements taken by MLS. In Fig. 15 we present the retrieval obtained for CO from band D scans. As can be seen in Fig. 15c, the information content of band D for CO is not particularly high and low CO values are found around 13 km along the whole flight. Low values are also found at lower altitudes for scans from 20 to 29. These values are in reasonably good agreement with the CO data predicted by the CLaMS model, even if the comparison of MARSCHALS CO data with the MLS/Aura ones (an example is reported in Fig. 16a for MARSCHALS scan 11), show that we still find slightly lower values around 150hPa (13 km).

In order to further analyse the capability of the MARSCHALS instrument to measure CO profiles, we report here also some results obtained during the mid-latitude test flight performed on 4 November 2009 (and then named TC9 flight). Unfortunately the TC9 flight was performed over an irregular flight path that prevents the optimal use of the measurements acquired in the limb-sounding geometry. In addition the analysis of the spectral response functions of the channeliser measured in the laboratory, performed after the TC9 flight, showed that one of the channels with variable spectral response function was located near the CO line (Spang et al., 2012), and for this reason a channeliser re-ordering was performed before the PREMIER-Ex Campaign (Sect. 2.2). However in Fig. 16b, we present the results obtained in the analysis of scan 8. The retrieved CO profile is in quite good agreement with MLS/Aura version 3.3 coincident data. The results obtained during the TC9 and the PREMIER-Ex Campaign highlight the MARSCHALS capability of retrieving CO. "

Moreover, we replaced Fig.13 of the discussion paper with Fig.16 of the revised paper in which we report the comparison of CO from MARSCHALS scan 11 of the PrEx 1 flight and scan 8 of the TC9 flight with MLS/Aura coincident CO profiles. The new figure is reported below together with its caption.

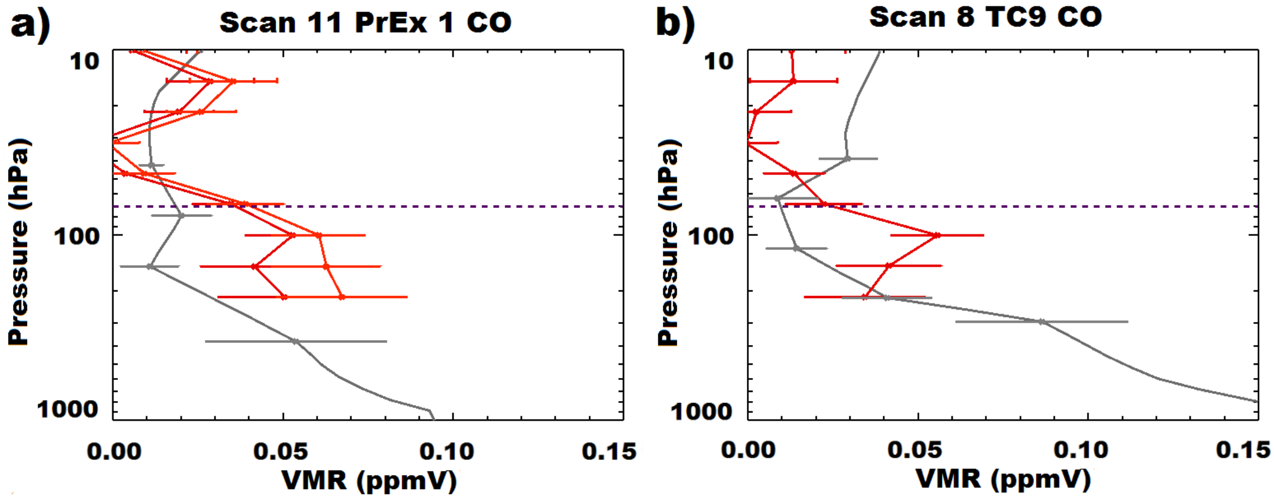

Fig. 16.(a) Comparison of CO profile retrieved from MARSCHALS scan 11 (grey) of PrEx 1 with MLS/Aura (red) CO profiles. (b) Comparison of CO profile retrieved from MARSCHALS scan 8 (grey) of TC9 with MLS/Aura (red) CO profiles. The horizontal dashed line represents the flight altitude level.

In order to specify that we used a realistic CH_3Cl profile, in Sect. 4.2 of the discussion paper we added in line 21 p.3144 of the revised text:
"The profiles of the other gases, not retrieved during the analysis, are extracted from the IG2 polar winter atmosphere. During the revision of this paper we realized that the IG2 data for CH_3Cl were overestimated. CH_3Cl emission in band D is very close to that of CO and a wrong profile may badly affect its retrieval. Therefore the CH_3Cl VMR profile below 20 km was inferred from MLS/Aura data measured in polar regions on the same date of the flight."

The noise error is not just a 1-sigma error. To get the measurement error, The system noise temperature T_sys is estimated (spectrally resolved) from the hot and cold counts. The noise error is then calculated according to the radiometric formula:

delta_t = T_sys / sqrt(integration_time * bandwidth)

Since estimating T_sys from the unwrapped channeliser counts is not straight forward, the noise level may be slightly affected by this estimate.

P3152L25: Is the radius a constant value or e.g. the median of some particle distribution (in that case the width should also be reported)?

The radius of cloud particle used into the MSSF module is constant, to clarify this in the revised text we replaced in line 22 p. 3152: " In particular, we used *R* and phase values ..." with: "In particular, we used a constant *R* value and phase ..."

P3152L27: Could you also report the value of the number density used?

In the revised text we reported the value of the adopted number density: we added "(N=0.35 cm^{-3})" in line 27 p. 3152 after "number density".

Technical

P3132L13: 'To overcome this, as part of the seventh call for Earth Explorer Core missions currently under evaluation in the frame of the European Space Agency (ESA)'s Living Planet Programme, one of the three mission candidates selected to enter Phase-A feasibility study is the mission "Process Exploration through Measurement of Infrared and Millimetre-wave Emitted Radiation" (PREMIER)'
Since the evaluation has taken place, this sentence should be updated.

In the revised text in line 13 p. 3132, we updated the sentence:
"To overcome this, as part of the seventh call for Earth Explorer Core missions currently under evaluation in the frame of the European Space Agency (ESA)'s Living Planet Programme, one of the three mission candidates selected to enter Phase-A feasibility study is the mission "Process Exploration through Measurement of Infrared and Millimetre-wave Emitted Radiation" (PREMIER)"
with:
'To overcome this, as part of the seventh call for Earth Explorer Core missions in the frame of the European Space Agency (ESA)'s Living Planet Programme, one of the three mission candidates that underwent Phase-A feasibility study was the mission "Process Exploration through Measurement of Infrared and Millimetre-wave Emitted Radiation" (PREMIER). PREMIER was not selected at the end of the evaluation process. Nonetheless, the strong scientific case and the technical feasibility demonstrated by Phase-A preparatory studies laid the basis to seek for a new launch opportunity either through national initiatives or in response to ESA Earth Explorer 9 Call for Ideas."

P3132L28: 'Respective infra-red instruments to demonstrate the IRLS capabilities are already existing, e.g. Michelson Interferometer for Passive Atmospheric Sounding – STRatospheric aircraft (MIPAS-STR), Gimballed Limb Observer for Radiance Imaging of the Atmosphere, AirBorne version (GLORIA-AB)'
Could you give references for those instruments?

For GLORIA we added the following reference both in line 2 p.3133 and in the "references" section:
Friedl-Vallon, F., Riese, M., Maucher, G., Lengel, A., Hase, F., Preusse, P., and Spang, R.: Instrument concept and preliminary performance analysis of GLORIA, Adv. Space Res., 37,2287–2291, doi:10.1016/j.asr.2005.07.075, 2006. 5531, 5533.

For MIPAS-STR we added the following reference both in line 1 p.3133 and in the "references" section:
Piesch, C., Gulde, T., Sartorius, C., Friedl-Vallon, F., Seefeldner, M.,W¨olfel, M., Blom, C. E., and Fischer, H.: Design of a MIPAS instrument for high-altitude aircraft, Proc. of the 2nd Internat. Airborne Remote Sensing Conference and Exhibition, ERIM, Ann Arbor, MI, Vol. II, 199–208, 1996.

P3148L22: 'hydropause' Correct to 'hygropause'

OK. In the revised text we replaced "hydropause" with "hygropause" in line 22 p. 3148.