<u>Reply to reviewer #1</u>

We thank Reviewer #1 for his/her helpful and very detailed comments and suggestion. We would like to point out that, unfortunately, the Reviewer commented the very first draft of the manuscript and not the revised version that eventually went on AMT Discussions. Therefore, some (very few in fact) of his/her comments do not apply anymore to the version published on AMTD.

In the following we address the Reviewer comments and indicate how we have changed the paper according to his/her recommendations.

<u>General comment</u>

I'm not familiar with the term "to/by the larger of". I don't think it's a used term, please verify/correct.
We checked it and confirm that this is a used expression.

<u>Major concern</u>

My major concern is Figure 7 (see comments below). This should be adjusted or a very convincing argument needs to be given for the choice of altitude levels.
We modified this figure according to Reviewer's suggestions. For detailed reply please see below (Figure 7).

Page 1
Line 16 : ..during the winters of..
Done.

Line 20 : 'to be the larger of' (see general comment)
Line 22 : 'to the larger of' (see general comment)
Please, see reply to general comment.

Line 25 : ..0.3 ppMv (8%) and 0.9 ppmv (18%)..
This was already fixed in the AMTD manuscript.

Page 2
Line 2 :'columns interannual and seasonal variations' : see comment on Page 13, Line 27.
This issue was addressed below under Reviewer's comments regarding Page 13, Line 27.

Line 11 : ..the main components of Polar Stratospheric..
Done.

Line 25-26 : ..that are at work in.. : strange formulation, maybe change to "that take place in.."
Done.

Line 30 : ..understanding of the mechanisms..
Done.

Page 3
Line 6 : 'especially while anthropogenic' : please rephrase.
We realized that this expression was unclear and removed it.

Line 23-24 : ..when well validated..
Done.

Page 4
Line 19 : ..trace gas concentrations..
Done.

Line 19-21 : add reference.
Done.

Line 27 : ..balance between the two beams..
This phrase was removed already in the AMTD manuscript.

Page 5
Line 1 : a compact cluster?
We changed this wording to "*single broad unresolved feature*".

Line 3 : ..contributes background curvature.. : what do you mean? please rephrase
The sentence has been modified and a sentence added to clarify the meaning. Now the paragraph reads: "*GBMS O_3 measurements discussed in this work are obtained by observing the pure rotational transition line at 264.925 GHz (Fig. 1a). The observed HNO_3 spectrum is more complex and characterized by a number of superimposed, relatively weak rotational lines centered at 269.240 GHz, appearing as a single broad unresolved feature in the spectrometer pass band due to pressure broadening (Fig. 2a). In this spectral window the wing of a strong O_3 line is also observed. This O_3 line is centered at 267.266 GHz, outside the GBMS pass band, but its signature is visible as a background curvature to the HNO_3 spectra.*"

Page 6
Line 8 : what do you mean with 'The amount of information that is added to x_a from the measurement'?
The retrieved profile is a weighted average of the information coming from the a priori profile and from the measurements. By the above sentence, we meant that the a priori information is available before the measurement is carried out. In this sense, the information coming from the measurement is "added" to x_a. We agree with the Reviewer that this sentence is unclear and, in response to this comment and to comments by Referee #2, we rephrased to "*The relative weight of the a priori profile and of the measured spectrum depends on the physical (forward) model included in **K**, as well as on the error covariances S_ε and S_a (in particular on the ratio S_ε to S_a rather than on their absolute values)*".

Line 21-24 : After applying a smoothing or as you mention at the end of Section 3.1, by 'convolving' the high resolution MLS profile (Eq. 2). Please rephrase to make your statement complete.
We rephrased this sentence following the Reviewer's recommendation.

Page 8
Line 4 : Please define x_r and x, maybe in combination with L5-6? Be consistent with Eq. 1.
Done.

Line 23 : Reference for forward model error?
The references for forward model errors are the same of those for errors due to instrument calibration and data scaling procedures. Thanks to the Reviewer's comment we realized that we did not call them from the correct place and moved the call to the end of the sentence.

Line 23/25 : 'data scaling errors' : see comment on Section 2.
This comment was addressed below under Reviewer's comment on Section 2.

Page 10
Line 2 : 'by the larger of' (see general comment)
Please, see reply to general comment.

Page 11
Line 7-21 : Please, do add your reference here (Sect. 3.11 Livesey et al. 2011?).
We thank the Reviewer for noticing this omission. We added the reference.

Page 12
Line 29 : Quantify selection criteria of a 'poorly fitted spectrum'.
We considered a spectrum "poorly fitted" if the RMS of its spectral residual is > 0.05 K. We added a sentence in the manuscript to clarify this point.

Page 13
Line 9-11 : 0.05 ppm : add the relative difference value in percentage (which is calculated how (relative to ?)? To remind the reader please add, in the figure (by a line or shading..), the vertical range (17 to 50 km) you considered the retrieval to be scientifically useful (as mentioned in Section 3.1).
Following the Reviewer's suggestion, we added the relative difference value in percentage and we specified, in the caption of Figure 3, that it is calculated by dividing the mean difference (GBMS-MLS) by the global mean (GBMS+MLS)/2.
In Figures 3 and 6, we also added a shaded area to set the limits of the vertical range where our retrieval has a good sensitivity (>80%) and can be considered for scientific use.

Line 19-20 : See comment on Figure 4.
Please, see reply to comment on Figure 4.

Line 27 : I don't understand how seasonal variations can be evaluated when looking at a 3 month-period ? Please clarify or adjust (also in the Abstract, last line).
By the expression "seasonal variations" we meant that we are able to evaluate variations in the trace gases concentrations occurring from winter to spring (or from inside to outside the vortex). We tried to clarify this point in the manuscript.

Page 14
Line 6-9 : As for O3, add, in the figure (by a line or shading..), the vertical range (17 to 45 km) you considered the retrieval to be scientifically useful.
Done.

Line 9 : And reaching quite high relative difference values (out of range in the figure, please adjust), any ideas why?

Above ~30 km, values of the relative difference between GBMS and MLS become quite large because HNO_3 concentrations decrease sharply, reaching nearly zero values. For this reason we think that showing the relative difference above 30 km is not particularly informative and have chosen, for figure readability, to cut-off the x-axis at ±40 %.

Line 10-11 : I don't understand what you mean here.

We rephrased this sentence and now it reads: "*The mean difference in absolute values between the two data sets remains within a standard deviation over the whole vertical range*".

Line 12-17 : See my comment on Figure 7.

Please, see reply to comments on Figure 7.

Page 16
Line 1-11 : See previous comments on Page 14 and Figure 7.
Please, see reply to comments on Figure 7.

Section 2
How is the spectrum calibrated (liquid nitrogen..?)? Here you only describe the beam-switching technique, please add a few words on how the spectrometer output signal is converted to a brightness temperature. In Sect. 3.1 you define errors in the receiver temperature (Trec) and opacity as so-called data scaling errors. A few sentences here on the calibration with at the same time a description of terms like Trec and opacity can make that section (3.1) clearer as well.

Following a suggestion by the Associate Editor, in the first revision of the manuscript we rephrased a few sentences and eliminated the whole paragraph about the beam-switching technique in order to shorten the description of the instrument. For consistency, we would prefer to refer to previous publications (de Zafra, 1995; Fiorucci et al., 2008) for a detailed discussion of the GBMS observing technique and involved equations (including calibration and data scaling procedures).

Section 3.1
I actually wanted to suggest to plot the errors in the figures in percentage instead of ppm. In the text you quantify the errors in percentage, but then the measurement noise in ppm. Be consistent, or add both (as you do at Page 10, Line 2)?
We followed both suggestions.

Section 3.2
Here you describe the different panels of Figures 1 and 2 very well (Line 20-26). Your discussion in Section 3.1, starting at Line 16 would be clearer with your description of panels f and g you give here. I suggest to transfer a few of these sentences from Line 20-26 to Section 3.1 (before Line 16).
We moved a couple of sentences describing panels e, f and g from section 3.2 to section 3.1, as suggested by the Reviewer.

Figure 1
(a-b) x-axis: Please put the exact frequency instead of channel number. Your simulated spectrum (red line) is hardly visible

Due to its double side band mixer, each spectrum observed by the GBMS is a superposition of two spectral windows of the same width and located at an equal distance in frequency (the IF) below and above the local oscillator frequency. Therefore, each point of the GBMS spectrum corresponds to 2 different frequencies. That's why we have always plotted GBMS spectra versus channel numbers (see also previous publications using GBMS datasets). However, in order to remind the reader of the frequencies observed, we added the information on the spectral pass band and lines observed in the captions of the two figures.

We used a thinner line for the simulated spectrum.

Figure 2
(a-b) x-axis: Here as well, please put the exact frequency instead of channel number.

Please, see previous reply.

Figure 4
I find it very difficult to distinguish between MLS and MLS convolved. Please use a different colour.
The label of the x-axis is cut off.
Done.

Figure 7
Same comments as for Figure 4 (label x-axis and colours MLS versus MLS convolved). This figure is not satisfactory. You're showing three levels every 4 km of GBMS data with a vertical resolution varying from 9 to 14 km. If you look at your averaging kernels, there's a great overlap of the information content you're showing here in the panels (especially 22 and 26 km). Why do you not show the same levels as for O3? It would be very interesting to see results for levels around 35-40 km.

In the HNO_3 time series we do not show the same levels as for O_3 but use the same criteria to choose them. For both gases we show three levels (near the peak, below it, and above it) in regions where the concentrations are large enough to show significant variations (in ppmv or ppbv). Moreover, even if the nominal vertical resolution is given by the FWHM of the Averaging Kernels and varies between 9 and 14 km, tests have shown that the GBMS retrievals typically locate the altitude of the profile peak to within ~2 km in the middle and lower stratosphere [de Zafra et al., 1997].

In order to address the reviewer's request, we slightly enlarged the vertical range displayed in this figure, plotting HNO_3 concentrations at 18, 24 and 30 km (instead of 18, 22 and 26). The new version of this Figure is shown below.

Figure 8
The symbols are very big, it makes it difficult to see the different datapoints.

We realized that the figure was unclear. The large crosses in Figure 8 (and 5) are not symbols. They are vertical and horizontal error bars that represent MLS and GBMS uncertainties.We added this information in the captions. We also modified the figures adding small circles as symbols.
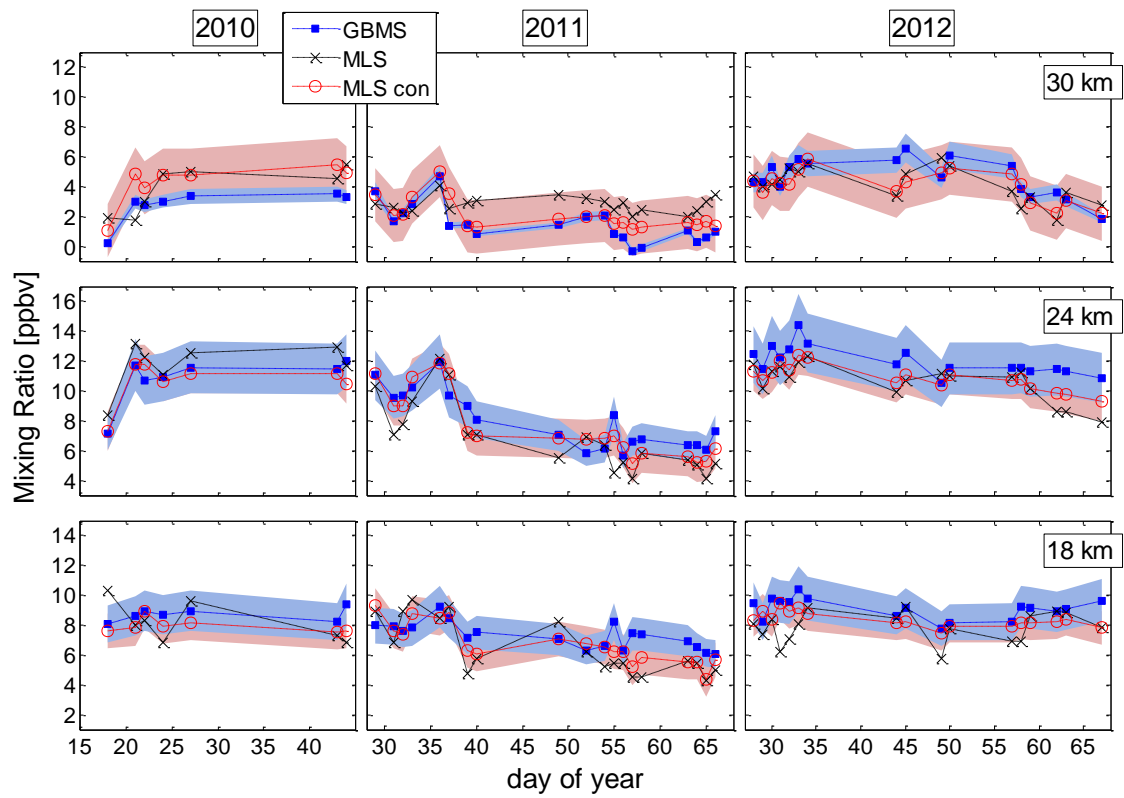
Figure 7. Same as in Figure 4, but for HNO$_3$ data. HNO$_3$ values are displayed at 18, 24 and 30 km altitude.