Author response

Gabriele Stiller et al.

Reviewer comments are in black, our replies are in blue, and the changes to the manuscript are in brown.

Reviewer #1

General Comments

The manuscript provides an overview of the new Version 8 MIPAS retrievals of CFC-11, CFC-12, and HCFC-22. The paper is very detailed, but I found it easy to read and that it provides excellent information both for readers interested in the retrieval process and potential users of the data. A comprehensive error analysis is also provided. In my opinion the manuscript is very useful to the community and can be published almost as is. I have provided some of my thoughts while reading through it that the authors can choose to consider if they wish.

We thank the reviewer for their positive and encouraging assessment. In the following we reply to each comment.

Specific Comments

p. 5: Figure 1: I find this figure a little difficult to follow. Clearly the retrieval involves a complicated flow of data. I don't know a better way of presenting it, but maybe the authors can think of something.

We agree that this figure is complicated. We have, however, not found a simpler way to communicate this information.

No changes to the figure except for corrections related to the issue with interfering gases discussed below under "Additional changes".

Sec. 3.1: Is the 2D temperature field used here? I see it mentioned in the CFC-11 section but not here.

Yes, the 2D temperature fields were used in the retrieval of all three species described here. We have added this information to the description of CFC-12 and HCFC-22.

For CFC-12, the information was already available in the previous version (l122 - 124). We have added "2D temperature field" in brackets to make it even clearer:

”Information on the horizontal temperature structure (2D temperature field), as available from the temperature and tangent altitude retrieval results (Kiefer et al., 2021) is also used for the CFC-12 retrievals.”

For HCFC-22, we have changed the sentence in l315/316 to:

”With respect to the general settings, i.e. the joint-retrieval of the background continuum and radiance offset, the new regularization, the vertical retrieval grid, and the use of a 2D temperature field, the V8 retrieval of HCFC-22 uses the same approach as chosen for CFC-11 and CFC-12."

p.6 l.140: "CFC-12 is retrieved on a vertical grid as follow:...": I see altitude here, presumably the altitude-pressure relationship is taken from a preceeding retrieval step? I don’t see it mentioned unless I missed it.

Correct. We retrieve temperature and line-of-sight pointing information in a preceding retrieval step (see Kiefer et al., 2021) and construct the pressure at the tangent altitudes and the retrieval grid points with one (z,p,T) reference point taken from ERA-I and by making use of the hydrostatic equilibrium. We have added this information to the revised paper.

We have changed the paragraph at lines 106 - 109 to:

”In our sequential retrieval approach, the retrieval of CFC-12 follows the retrieval of temperature and the line-of-sight pointing information .... where relevant. The pressure at the tangent altitudes and the retrieval grid points is constructed with one (z,p,T) reference point taken from ERA-I and by making use of the hydrostatic equilibrium (Kiefer et al., 2021).”

p.6 l.142: "This implies that the involved inverse problem is ill-posed...": I understand what the authors mean, and it is certainly true if a single spectral point was used, but the use of multiple spectral points can result in a problem that is well-posed with a spacing finer than the measurement spacing.

We agree that, due to spectral line-shape information, the system of equations to be solved is not underdetermined. However, in the case of MIPAS, the atmospheric line shape is, due to the instrument line shape function and Norton-Beer strong apodization, not fully resolved. The set of equations to be solved in the inversion is not fully linearly dependent, but it includes equations that are almost linearly dependent. This leads to a situation where the inversion is very unstable, and a tiny distortion of the measurement will lead to an enormous change in the result. This is what we call ”ill-posed”. For (H)CFCs the situation is even worse, because in the radiative transfer calculation the lineshapes are not evaluated explicitly as a function of pressure and temperature, but lab-measured absorption cross-section spectra, available at a limited number of pressure-temperature combinations, are simply interpolated to the actual pressure and temperature. Since we are not sure if our use of the term ”ill-posed” is exactly compliant with the definition by J. Hadamard (”Sur les problèmes aux dérivées partielles et leur signification physique”, Princeton University Bulletin Vol. 13, No 4, pp. 49–52, 1902), we have used a somewhat weaker wording: ” ... tends to be ill-posed ...”.

We have changed the sentence on page 6, line 142/143 to:

”This implies that the involved inverse problem tends to be ill-posed and has to be stabilized by regularization.”

Sec. 3.4: Presumably here "nominal geolocation of the limb scan" is calculated based off of the 30 km tangent point? If you were to calculate horizontal displacement relative to the geolocation of each individual’s spectra tangent point is it essentially 0? I’m mostly wondering if it would be better to compare the MIPAS measurements to models by sampling the model at each spectra’s tangent location rather than the nominal location.

Yes, your understanding is correct and the displacement is meant with respect to the nominal geolocation of the limb scan at about 30 km altitude. However, the displacement calculated here is **not** identical to the displacement of the tangent point of each individual spectrum in the scan. Instead, the displacements are often larger and are the combined effect of the tangent point displacement, the non-linearity of radiative transfer, and the crosstalk with regularisation in the vertical domain. Since the displacements of individual tangent points do not help to overcome the problem regarding comparisons to models, we prefer to stay with our presentation relative to the nominal geolocation of the limb scan.

No changes to the manuscript.

Sec. 3.6: My understanding is that essentially another iteration of the retrieval is performed with an adjusted grid to get the ML profile, I assume this is only done for CFC-12 and not for any of the input data? Can the change in averaging kernel of temperature for example have an influence on this coarse grid product?

In order not to propagate an unnecessary smoothing error of temperature onto the target gas coarse grid retrieval, we use the fully resolved temperature from the regular retrieval for the coarse grid gas retrievals. A changing temperature profile might indeed affect the coarse grid profile, but this is a higher order effect.

No changes to the manuscript.

Sec. 4.5: Can you speculate on which changes in the retrieval had the largest impact on the differences?

We have tested the retrieval by just exchanging the spectroscopic data, but leaving everything else, including the version of the measured spectra, as in the previous V5 retrieval. The change of spectroscopic data alone accounts for a reduction of about 4% over the altitude range of the profile up to $\sim$25 km. Additional changes of parameters (new level-1b data, the 2D temperature field, better information on pre-fitted constituents or a priori information on interferents) contribute another 2 to 5% of difference between V5 and V8 CFC-11. We have added this information to the revised version of the manuscript.

We have extended the sentence at line 180/181 as follows:

”Compared to CFC-12, the differences between V8 and V5 CFC-11 mixing ratios are larger. Test retrievals with V5 spectra, for which only the spectroscopic data were exchanged, everything else unchanged, led to a reduction of about 4% over the altitude range of the profiles up to ∼25 km. Additional changes of parameters (new level-1b data, the 2D temperature field, better information on pre-fitted constituents or a priori information on interferents) contributed another 2 to 5% of difference between V5 and V8 CFC-11.

Reviewer #2

General comments:

The manuscript of Stiller et al. (2023) describes the new Version 8 (V8) of MIPAS CFC-11, CFC-12 and HCFC-22 measurements. The changes performed in the retrieval processes between the previous version (V5) and V8 are very well detailed and justified, and the improvements observed in the resulting data sets are substantial. The data are well characterized by their averaging kernels and uncertainties, and furthermore the authors introduce a new representation of their products on a coarser grid which will be very useful for the users.

Therefore, providing a description of these new V8 data sets is important for the scientific community and well in the scope of AMT. I recommend the publication in AMT, and I list some questions and suggestions below that might help clarifying a few points.

We thank the reviewer for their positive and encouraging assessment. In the following we reply to each of their comments.

Specific comments:

- p.3 Section 2 Description of MIPAS modes: It was not clear to me why while the NOM modes have two versions (FR and RR before and after Jan 2005 respectively), the MA has only one mode. I had to find some MIPAS documentation to see that the MA only started in Jan 2005 (right ?), so maybe put this information in the text here, for MIPAS non-expert.

Agreed.

We have changed line 83 - 86 to: "MIPAS measurement modes include the Nominal mode (NOM, with tangent altitudes from 6 to about 70 km, depending on latitude), the Upper Troposphere Lower Stratosphere mode (UTLS-1, 5.5 – 45 km), the Middle Atmosphere mode (MA, 18 — 102 km), the Upper Atmosphere mode (UA, 42 — 172 km) and the Noctilucent Cloud mode (NLC, 39 — 102 km) (Oelhaf, 2008), with the MA, UA, NLC and UTLS-1 observation modes available only for the RR phase of the mission. For CFC-12, CFC-11, and HCFC-22, only the NOM, UTLS-1 and MA modes are relevant, ...".

- p.4 CFC-12, l.96: "v5 CFC-12 might have a slight low bias"; and "Zhou et al. found good agreement": Can you be more specific and give numbers? To check that v8 is an improvement, ideally one would like to see some validation of v8 in this manuscript. If not possible but the authors (unless you could consider it?), providing numbers (and sign of the bias) could help to check more quantitatively that there will be an improved agreement with the new version.

We think that additional validation would make this paper too long. We plan to provide the comparison with CFC observations from other instruments as a forthcoming paper. Nevertheless, we are now more specific and provide numbers on the differences of the v5 versus v8 data versions, in context with biases found for the v5 data versions.

We have changed the text in lines 94 - 97 to:
"These authors reported good agreement between MIPAS profiles and those of the comparison instruments with differences exceeding $\pm$ 10% only in very few cases below 25 km altitude. Above, comparisons to the various other data sets seemed to agree on a rapidly increasing low bias that reaches, e.g. for comparison with ACE-FTS v3.5, -30% at 32 km. Zhou et al. (2016) compared MIPAS CFC-12 and ground-based Fourier transform infrared (FTIR) spectroscopic measurements at Réunion Island. They found a low bias of -2.9% and a standard deviation of 4.6 % (in terms of (MIPAS - FTIR)/FTIR$\times$100 [%]) between partial columns from MIPAS CFC-12 and the ground-based FTIR measurements."

- p. 5, figure1: I find it hard to follow. Maybe you could use different colors for the arrows concerning the 3 different species, or consider making 3 different schemes?

The problem with different colours is that we use colour coding for the different categories of data (i.g. database, V5, V8) already. Beyond this, some arrows issue into other arrows, that is to say, some arrows represent two or more species. We thus prefer to leave the figure as is.

No changes to the manuscript.

- p.10-14: Fig. 2 to 7: I would merge these 6 figures into 2 figures (Fig. 2 to 4; and Fig. 5 to 7). In Figs. 5-7, the legend describing what is the black lines/points is missing. Of course, the same remarks for the other species.

We have combined the figures as suggested (for the other species as well). For Figs. 5 to 7 we have explained that we have coloured only every 5th averaging kernel row, and the black lines are all averaging kernel rows for the retrieval grid altitudes in between.

We have combined Figs. 2 to 4, 5 to 7, 11 to 13, 14 to 16, 18 to 20, and 21 to 23 into 3-panel figures each, and have added the explanation for the black lines and diamonds in the figures of the averaging kernels as follows: "Every fifth averaging kernel row is marked by color, and the diamonds mark the altitude of the retrieval grid point."

- Sect 3.4: Table 4: Maybe a Figure as in von Clarmann 2009a would be nicer than numbers in a Table? Unless the authors think the exact numbers would be used by the community? They can decide. Same remark for Table 8 and 12.

We prefer to stay with the table and the numbers. Reviewer#1 made the point that model comparison could be done at the exact geolocation of the values along the vertical profile, which requires exact knowledge of the numbers.

No changes to the manuscript.

- p. 13 l.182-183: "The horizontal smearing…is always narrower than the… horizontal distance between the nominal geolocations of two subsequent limb scans": can you give this horizontal distance in the text?

We have added this information. For the FR phase the horizontal distance was about 500 km, while for the (NOM/MA/UTLS1) mode of the RR phase it was (410/430/290) km.

We have changed the text from line 86 on into: "For CFC-12, CFC-11, and HCFC-22, only the FR and RR NOM, UTLS-1 and MA modes are relevant, because the part of the atmosphere seen by the UA and NLC modes contain no appreciable amounts of these gases. The along-orbit distance of two adjacent profiles for FR/NOM, RR/NOM, UTLS-, and MA measurement modes was 510, 410, 290, and 430 km, respectively. Data presented ..."

- p. 13, Sect. 3.5:

1) The authors describe the effect of new version vs v5 in term of profiles (biases, avoided negative vmr). How the uncertainty and the vertical and horizontal smoothings change from v5 to v8? Are they also improved or similar? Same question for the other species.

We now discuss changes in the vertical resolution and the spectral noise-induced uncertainty in the revised version in detail. In short, major changes occur for CFC-11 only. Here we have reduced the regularisation above 20 km in order to improve vertical resolution. This is now better than 3.5 km up to about 30 km altitude, but deteriorates rapidly from there on. As a result, the retrieval uncertainty due to noise in the spectra increases from about 6 pptv below 16 km up to 10 pptv at 30 km and larger above (see Figs. 11 and 12 in the manuscript, red line with crosses). For CFC-12 the vertical resolution and the noise error are similar to the v5 data version. For HCFC-22, vertical resolution and noise error were both slightly improved (however, by less than 0.5 km and less than 1 pptv, respectively) by using more spectral grid points in the retrieval as described in Section 5.1.

For CFC-12, we have added after "cover a smaller altitude range than version V5." in line 200: "However, in the nominal range (up to 30 – 45 km, depending on latitude, see Fig. 4, top left panel) the vertical resolution and retrieval uncertainty due to noise in the spectra are similar to the V5 data version."
For CFC-11, we have added after line 285: "Another characteristic of the V8 retrievals is a reduced regularisation above 20 km in order to improve vertical resolution. This is now better than 3.5 km up to about 30 km altitude, but deteriorates rapidly from

there on. As a result, the retrieval uncertainty due to noise in the spectra increases from about 6 pptv below 16 km up to 10 pptv at 30 km and larger above (see Fig. 7, red line with crosses)."
For HCFC-22, we have added after line 368: "The vertical resolution and noise error could both be slightly improved (however, by less than 0.5 km and less than 1 pptv, respectively) by using more spectral grid points in the retrieval as described in Section 5.1."

2) The authors give in the text some numbers for systematic differences between the 2 versions. Would it be possible to give some visualization of these changes? Some maps v5 vs v8 or a map of differences? It could be in a Supplement if the authors do not want to increase too much the size of the paper. Same remark for the other species.

Now we provide timeseries of differences (as latitude-time cross sections for specific altitudes) for all three species for illustration.

We have added figures for the comparison to the V5 data version (new Figs. 6, 10, and 14); they show the timeseries of V5 CFC-12, CFC-11, and CFC-22, respectively, as latitude over time at specific altitudes, and the differences to V8. However, these can only be examples. We have added text as follows:

- For CFC-12 we have changed the text to: "The first row of Fig. 5 presents an average altitude-latitude cross section and a global map at 15 km altitude for an arbitrarily selected month of August 2011, while Fig. 4 (first row) shows the evolution over time at 10 and 14 km altitude of CFC-12. Differences between the new version V8 and the preceding version V5 are quite small (see Fig. 6), except for the lowermost parts of the profiles. In the previous data version volume mixing ratios at altitudes below 11 km were found to be lower in the tropics than at high latitudes (but only when represented at altitude levels, not at pressure levels) while V8 data are highest at the tropics and lower at the poles on both altitude and pressure levels. For FR retrievals, differences between V8 and V5 are typically around -2 to +4% in the troposphere. In the stratosphere, they vary between -6% under southern polar winter/spring conditions and around 18 km for 30°N to 30°S, and +3% elsewhere. The RR data set reveals other systematic differences between V5 and V8. Except for the stratospheric polar winter/spring conditions, where the V8 data set is about 4 to 12% lower than the V5 data version, the differences range between +4 and -2% over the full valid altitude range. Again, CFC-12 vmrs are reduced in the tropical tropopause region. The reduction at low latitudes around the tropopause for both FR and RR data is related to the reduction of an implausible maximum of CFC-12 in the uppermost tropical troposphere in the V5 data version."
- For CFC-11 we have changed the text to: "The differences between V8 and V5 data of CFC-11 vary strongly with latitude and altitude. In the lower part up to about 16 km altitude differences as shown in Fig. 10 are typical: Negative differences up to -5% at high latitudes and in the inner tropics, and positive differences up to 5% in the midlatitudes; further, the positive differences of V8 in the mid-latitudes increase over time, which leads to a reduction of the negative trend in these regions (Kellmann et al., 2012). Suspiciously high CFC-11 abundances in polar spring in V5 data are

removed in the V8 data. Towards higher altitudes, the pattern of differences changes gradually to a high bias of up to 5% in the tropics, and a low bias up to -40% in the mid- to high latitudes, and occasionally even stronger negative biases in the polar winter vortices.

– For HCFC-22, we have changed the text to: ”The differences are largest on an absolute scale with -25 pptv in the tropopause region, and decrease to -5 pptv at the lower and the upper end of the profiles (-3% in the middle troposphere to -12% in the tropopause region, and -13% in the upper stratosphere). Changes are even larger for the FR phase of the mission, with up to -20% in the polar regions (See Fig. 14, lower panel).

3) Is V8 closer to other reference measurements (does the bias given in this section go in the good direction with similar values than observed bias in the literature?) What is the impact of the new spectroscopy for CFC-12? Since it is the dominant systematic source of uncertainty, does it affect the bias here? Or is it only the regularization that matters more for this species?

Reviewer #1 had a comment pointing in the same direction. Now, we provide numbers on the differences of the v5 versus v8 data versions, and put them in context with biases found for the v5 data versions. And we discuss the impact of the new spectroscopy in more detail.

Regarding the biases identified within validation of V5 data, and the changes in the new data version, we have added the following:

– For CFC-12, we have added: ”While comparisons to reference data below 20 km remained inconclusive (see Eckert et al., 2016, their Figure 31), they seemed to agree on a low bias of MIPAS V5 CFC-12 increasing rapidly to -6% at 25 km and -30% at 32 km. The difference CFC-12 V8 - V5, developing from negative values at the tropopause to about +4% at 25 km, corrects the CFC-12 data record in the right direction.”

– For CFC-11, we have added: ”Eckert et al. (2016) found, in general, a high bias of 5 to 20% at the lower end of the CFC-11 V5 profiles. Due to the strong latitude dependence of biases between V8 and V5 it is hard to come to an unambiguous conclusion wether V8 is an improvement or not. However, we note that the supposedly artificial maxima of the profiles in the tropical upper troposphere/lower stratosphere region are less pronounced in version 8 (see Fig. 4), and the suspicious volume mixing increase towards the poles in the lower part of the profiles of V5 CFC-11 (see Fig. 10, upper panel) is also less pronounced in version 8 data. Beyond this, version 8 covers a wider altitude range. The CFC-11 vmr bias between the FR and RR MIPAS mission phases is considerably reduced, particularly at low altitudes (see Fig. 10).

– For HCFC-22 we have added: ”These changes do not agree with v3.5 ACE-FTS-measurements but they improve the comparison with cryosampler measurements (see Chirkov et al., 2016, their Figures 8 and 9).

Regarding the impact of the new spectroscopy, we have added:

– for CFC-12, after line 200: ”The changes due to the new spectroscopic data used for the V8 retrievals, derived from tests with V5 spectra for which only the spectroscopic data were exchanged, are rather small. They are restricted to the troposphere and UTLS region and are in the order of 5 to 8 pptv (about 1 to 1.5%)”

– for CFC-11, after line 289: ”Test retrievals with V5 spectra, for which only the spectroscopic data were exchanged, everything else unchanged, led to a reduction of about 4% over the altitude range of the profiles up to ∼25 km. Additional changes of parameters (new level-1b data, the 2D temperature field, better information on pre-fitted constituents or a priori information on interferents) contributed another 2 to 5% of difference between V5 and V8 CFC-11 (see Fig. 10).”

– for HCFC-22, we have changed the first sentence of Section 5.5 to: ”V8 HCFC-22 mixing ratios are generally lower than V5, particularly in the tropical upper troposphere. The major part of this difference is due to the new spectroscopic data used (Harrison, 2016). The differences are largest on an absolute scale with -25 pptv in the tropopause region, and decrease to -5 pptv at the lower and the upper end of the profiles (-3% in the middle troposphere to -12% in the tropopause region, and -13% in the upper stratosphere). These changes ...”;

4) I find it hard to see an improvement in the step between FR and RR by simply looking at Fig 9 and at Fig 12 of Kellmann et al. (2012). Because this is an important improvement for users and a strong motivation to change from v5 to v8, would it be possible to show this result more clearly? E.g. some examples of time-series with an automatic step detection and some numbers given for the bias before / after Jan 2005 for the v5 and v8? Same remark for CFC-11 (p.25,l. 185).

Analyses of the V8 vs. V5 differences provided that the step (bias) between FR and RR data was reduced in some cases where it was quite large in the V5 data version, but it has not improved everywhere. Therefore we weaken our statement, while we add time series for some example altitudes, as well as timeseries of differences between V5 and V8 (Figs. 6, 10, and 14 in the revised version of the manuscript).

We have added (new) Figs. 6, 10, and 14 for CFC-12, CFC-11, and HCFC-22, respectively, that show the V5 time series and the differences to V8. We have changed the text as follows:

– For CFC-12: ”Analysis of the differences between V5 and V8 timeseries (example given in Fig. 6) reveals that the steps between the FR and RR parts of the V8 CFC-12 data record have been reduced for some prominent cases in the V5 data set; however, in general, some biases between the two mission phases still remain in V8 data. Nevertheless, we consider the V8 data as more realistic.”

– For CFC-11: ”The CFC-11 vmr biases between the FR and RR MIPAS mission phases are reduced for some prominent cases (see Fig. 10). However, the V8 CFC-11 data set still reveals steps between the FR and RR phase, that are partly due to the different vertical resolution caused by the differing vertical sampling in the two phases. ”

– For HCFC-22: ”Regarding the two mission phases of MIPAS, the V8 dataset seems not to be fully homogeneous, but reveals steps of about 5 pptv from the V8H_F-22_61 (FR) to the V8R_F-22_261 (RR) data.”

- p.17, Fig. 10: could be merged with Figs. 17 and 24.

We prefer to leave the Figures separated. By this, the figures are closer to the place in the manuscript where they are called. We have reduced the number of figures already by combining the error budgets and averaging kernels for each species.

No changes to the manuscript.

- p. 18, l. 222-227: Similar remark as above for CFC-12 p.4: the authors should give numbers of the observed bias in v5. And/or perform new validation here using reference measurements.

We think that additional validation would make this paper too long. We plan to provide the comparison with CFC observations from other instruments as a forthcoming paper. Nevertheless, we are now more specific and provide numbers on the differences of the v5 versus v8 data versions, in context with biases found for the v5 data versions.

See above, replies to reviewer comments on Section 3.5

- p. 24, l.268-269: use FR, HR and MA as elsewhere (instead of “high resolution measurements,. . .) ?

This sentence has been changed to ”All said on the purpose of vertical averaging kernels in the context of CFC-12 also holds for CFC-11, whose vertical averaging kernels are shown in Fig. 9.” We have made sure that FR, RR, and MA has been used throughout the manuscript.

- p. 25, Sect.4.5:

1) Same remark as for CFC-12: hard to visualize how much the data set is improved without additional maps (e.g. the reference of Fig.8 is given, but we don’t have the same fig. for v5 in order to compare).

See above, replies to reviewer comments on Section 3.5, item 1)

2) Same remark for the step reduction between FR and RR as above (hard to see only by looking at Kellmann et al., 2012).

See above, replies to reviewer comments on Section 3.5, item 2)

3) What is the part of the improvement that is due to the change of spectroscopy? What is the main driver of the improvement in the bias between FR and RR?

We have tested the retrieval by just exchanging the spectroscopic data, but leaving everything else unchanged, including the version of the measured spectra, as in the previous V5 retrieval. The change of spectroscopic data alone accounts for a reduction of about 4% over the altitude range of the profile up to ∼25 km. Additional changes of parameters (new level-1b data, the 2D temperature field, better information on pre-fitted constituents or a priori information on interferents) contribute another 2 to 5% of difference between V5 and V8 CFC-11. We will add this information to the revised version of the manuscript. Regarding the step between FR and RR data, we think that the improved temperature information (including the 2D fields) is a major contributor to the improvements of the retrievals. Further, any improvement in the retrieval chain before CFC-11, that affects the CFC-11 spectral region will contribute to an improved CFC-11 retrieval.

See above, replies to reviewer comments on Section 3.5, item 3)

-p. 36, Sect. 5.5:

1) The maximum in the upper troposphere due to the old spectroscopy is also present in ACE-FTS and ground-based data using the same spectroscopy ?

We have checked ACE-FTS v3.5 versus 4.1 data. ACE-FTS retrievals have used the new spectroscopic data provided by Harrison (2016) from v4.0 on. There is a difference between the two data versions, with v4.1 being lower in general than v3.5. However, the data are too noisy to detect or exclude a maximum in the tropical upper troposphere. We need to keep in mind that the coverage of the Asian monsoon by ACE-FTS data is sparse. Ground-based remote sensing data have typically a too coarse vertical resolution for such a small-scale feature in the profiles. We have compared to tropical in situ data, however, we could not compare to data obtained in the Asian monsoons (presumably, there are none, or at least, we are not aware of any).

No changes to the manuscript.

2) Again, hard to see the improvement without appropriate v5 map/figure.

See above, replies to reviewer comments on Section 3.5, item 2)

- p. 37, Conclusions, l. 396-397: “Several implausible features in the V5 data.... Have disappeared or... reduced”. As said above for the 3 individual results sections, I think that giving concrete examples of these features present in v5 in figures or maps, then with the same examples “resolved” using v8, would help the visualization of the improvements.

We have now referred directly to the concrete examples of ”implausible features” given earlier, and have changed this part of the conclusions to the following: ”The MIPAS CFC-11, CFC-12, and HCFC-22 data record extends over ten years, covering the upper troposphere and stratosphere with a vertical resolution of about 3 km and a dense daily global coverage including dark polar winter conditions. We have presented the retrieval and the data characteristics (error budget, vertical and horizontal resolution) for the V8 data version retrieved with the IMK-IAA MIPAS data processor which is, most likely, the final data version. We consider the V8 data of CFC-12, CFC-11, and HCFC-22 as superior over V5 for several reasons:

– The V8 calibration including the correction for the detector aging is superior over V5 calibration, reducing instrumental drifts in the data.

– The new spectroscopic data used cover better the temperature-pressure range of the atmosphere.

– In all three cases, the V8 dataset is corrected with respect to V5 in the direction that is given by the V5 validations.

– Several implausible features in the V5 CFC-12 data, which could not be explained by any known atmospheric process, have disappeared in V8 or are at least largely reduced. These are: the CFC-12 V5 distributions over latitude in the middle troposphere (below 10 km) showed a minimum in the tropics and largest values near the poles while the V8 distributions now look as expected (larger values in the tropics and the Northern hemisphere); an implausible maximum of CFC-12 in the uppermost tropical troposphere in the V5 data version is reduced; areas in the upper stratosphere with negative CFC-12 VMR are reduced due to an adjusted regularization; in some prominent cases, the bias between the FR and the RR phase of the data set was reduced, however, in general, steps between the two phases could not be avoided.

– For CFC-11, suspiciously high abundances in polar spring in V5 data are no longer present in the V8 data; the supposedly artificial maxima of the CFC-11 profiles in the tropical upper troposphere/lower stratosphere are less pronounced in V8.

– For HCFC-22, the high bias of 10% (RR) to 20% (FR) versus cryosampler data detected for V5 HCFC-22 has disappeared; the isolated HCFC-22 maximum in the upper troposphere is largely reduced on a global scale, compared to V5 data. In the Asian monsoon, however, this maximum remains and can be explained by transport and uplift of HCFC-22 rich air from the industrial production sites in SE Asia (Vogel et al., 2016; 2019).

Additional changes:

In Tables 10 and 11, we have corrected an incorrect entry for COF_2; the entry now reads:

vmr(COF_2)	6.67E-06 - 6.94E-05 ppmv	database	Kiefer et al., 2002	P(7;11)

During the revision process, we found some minor bugs in the computer code for the calculation of the errors that affect entries in the tables and figures referring to the error assessments. All tables and figures (including those in the supplements) have been replaced by corrected versions. The difference to the previous, erroneous versions, however, is small, and none of the conclusions are affected.

Unfortunately, in the original manuscript CH_3Cl was erroneously listed as an interfering gas of the HCFC-22 retrieval. However, it has no signal in the HCFC-22 analysis windows. We have removed it from the tables and Fig. 1. In the error estimation, its contribution was zero anyway.

$CHCl_3$ was mislabelled CH_3CCl_3 in the original manuscript. This has been corrected in the text, tables and Fig. 1.

A paper on ACE-FTS v5.2 HCFC-22 was recently posted on the EGUsphere preprint server. Since this paper provides comparisons between ACE-FTS v5.2 and MIPAS v8, we have changed the following sentence from Section 5.5, line 365 - 368:

”Comparison to more recent ACE-FTS data versions that will use the absorption cross-sections by Harrison (2016), too, will provide more insight (see Kolonjari et al., Validation of ACE-FTS HCFC-22 concentrations in the upper troposphere – lower stratosphere, submitted to AMT, 2023).”

to

”Very recently, however, the ACE-FTS v5.2 data version became available, for which the HCFC-22 retrievals had also been performed with the spectroscopic data provided by Harrison (2016). Comparison between ACE-FTS v5.2 and MIPAS V8 HCFC-22 revealed good agreement (Kolonjari et al., 2023). For six 30° latitude bands, differences between ACE-FTS and MIPAS were within $\pm$ 5% (relative to ACE-FTS data) between 10 and 22 km. Above and below this range, MIPAS was between 0 and 10% lower than ACE-FTS. ”

In the description of the CFC-12 retrieval (Section 3.1) we have added information about the a priori profiles as follows (after line 146):

”The a priori profile is chosen as constant zero over the full altitude range, in order not to imprint any altitude structure on the retrieved profile. Since the regularization chosen employs a smoothing constraint only, results are not pushed towards zero, except for the uppermost altitudes where there is a diagonal term in the regularization matrix.”

For the description of the CFC-11 (section 4.1) and HCFC-22 retrieval (section(5.1) we have included:

”The general retrieval setup used for CFC-11 resembles that of CFC-12 described in the previous section, including the treatment of the background continuum and the additive radiance offset as well as regularization, **a priori profile**, the altitude grid of the retrieval, and the use of 2-dimensional temperature fields.”

and

”With respect to the general settings, i.e. the joint-retrieval of the background continuum and radiance offset, the new regularization, **the a priori profile**, the vertical retrieval grid, and the use of a 2D temperature field, the V8 retrieval of

HCFC-22 uses the same approach as chosen for CFC-11 and CFC-12."

References

Kiefer, M., von Clarmann, T., Funke, B., García-Comas, M., Glatthor, N., Grabowski, U., Kellmann, S., Kleinert, A., Laeng, A., Linden, A., López-Puertas, M., Marsh, D. R., and Stiller, G. P.: IMK/IAA MIPAS temperature retrieval version 8: nominal measurements, Atmospheric Measurement Techniques, 14, 4111–4138, https://doi.org/10.5194/amt-14-4111-2021, 2021.